Skip all front matter: Jump to Page 1

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TECHNICAL REPORT

Lightening Body Armor

Arroyo Support to the Army Response to Section 125 of the National Defense Authorization Act for Fiscal Year 2011

Kenneth Horn • Kimberlie Biever • Kenneth Burkman • Paul DeLuca
Lewis Jamison • Michael Kolb • Aatif Sheikh

RAND ARROYO CENTER

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Preface

The body armor that U.S. forces wear in Afghanistan is effective against ballistic threats: There have not been any known penetrations of the body armor or fatalities when the currently issued body armor was struck by projectiles it was designed to stop. However, the combat loads that dismounted soldiers and marines carry on patrol are very heavy, and a large portion of this load is due to body armor.

Congress asked the question, How can body armor weight be reduced? Congress's perception is that the Department of Defense has been slow in developing and deploying lighter-weight body armor. In Section 125 of the National Defense Authorization Act for Fiscal Year 2011, Congress requested that a federally funded research and development center conduct a study of lightening body armor. RAND Arroyo Center was selected to perform this study and was sponsored by Dr. Scott Fish, Army Chief Scientist, Assistant Secretary of the Army for Acquisition, Logistics and Technology.

This document should interest those involved with lightening body armor and the combat loads of dismounted soldiers and marines.

The research was conducted in RAND Arroyo Center's Force Development and Technology Program. RAND Arroyo Center, part of the RAND Corporation, is a federally funded research and development center sponsored by the United States Army.

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Contents

Figures and Tables

Figures

Tables

Summary

The body armor that U.S. forces wear in Afghanistan is effective against ballistic threats: There have not been any known penetrations of the body armor or fatalities associated with the threat of projectiles that the currently issued body armor is designed to stop. The body armor is heavy, however, constituting approximately 30 percent of the total load that is carried into combat by a dismounted soldier or marine.

Congress has asked the question, How can body armor weight be reduced? Congress's perception is that Department of Defense (DoD) has been slow in developing and deploying lighter-weight body armor. In Section 125 of the National Defense Authorization Act for Fiscal Year 2011, Congress requested that a federally funded research and development center conduct a study of lightening body armor. The RAND Arroyo Center was selected to perform this study.

The study focus is on soldier protection from ballistic threats—both small arms fire and fragmenting munitions. The study concentrates on reducing the weight of the torso armor, since most of the body armor weight is in protecting the torso area of the body. Protection of the torso area is provided using soft body armor vests with ceramic plate inserts, and the ceramic plates are heavy. The weight range of a full-up torso body armor set is 27 to 38 pounds for small to extra-large sizes.

Body armor must be capable of meeting two requirements. First, the ceramic plates cannot be penetrated when struck by multiple ballistic rounds in a well-defined shot pattern. Second, the backface deformation (a surrogate measure of blunt force trauma) that occurs when the bullet impacts the ceramic plate must be no greater than 44 mm, as measured by indentation depth in the test material backing the plate. This depth is based on limited 1977 research using anesthetized animals. Additional mathematical modeling predicted that a backface deformation of 44 mm or less would result in a maximum 10 percent probability of lethality.

Comparison of Approaches

The four approaches to lighten body armor—refining requirements, using modular configurations, improving testing, and improving materials—are compared in Figure S.1. In some respects, refining requirements is the most difficult approach to implement: Changing the processes necessary to meet requirements is not very difficult, but the decision to change requirements in the first place is. A change from the currently accepted threat round that the body armor must be capable of stopping to a less capable round (in terms of muzzle velocity, bullet type, or caliber) would have serious consequences if the change were later shown to be unwarranted and additional lethal casualties result.

Figure S.1
Comparison of the Four Approaches to Reducing Body Armor Weight

Approach	Ease in Executing Change	Required Army Coordination	Estimated Weight Reduction	Comment
Refine requirements	Moderately difficult	DCS G-3, TRADOC	**Small to moderate (~10–20%)**	Consequence great if wrong
Use modular body armor configurations	Easy in principle	Field commanders, TRADOC	**Moderate to large (~20–45%)**	Questions remain about risks
Improve testing	Moderate	PEO Soldier, ATC	**Small (~5–10%)**	Requires coordination with other services, DLA, and SOCOM and DOT&E approval
Improve materials (R&D, procurement process)	Moderate (funding)	ASA(ALT), DCS G-8	**Unknown at present**	Long-term solution; appropriate procurement process depends on technological challenge

NOTES: TRADOC = U.S. Army Training and Doctrine Command; PEO = Program Executive Office; ATC = Aberdeen Test Center; DLA = Defense Logistics Agency; SOCOM = U.S. Special Operations Command; DOT&E = Office of the Director, Operational Test and Evaluation; R&D = research and development; ASA(ALT) = Assistant Secretary of the Army (Acquisition, Logistics and Technology); DCS = Army Deputy Chief of Staff.

RAND *TR1136-S.1*

The least difficult approach is the use of modular body armor configurations, simply because the decision to use modular body armor has already been made. However, this approach carries the largest risk. If a commander decides to use a less effective body armor configuration (i.e., a lower level Body Army Protect Level [BAPL]) and his choice proves to be incorrect, avoidable casualties could result. The other two approaches we considered—improving testing and improving materials—involve some difficult choices but should not lead to catastrophic outcomes.

Each of the approaches requires Army and broader DoD coordination before it can be implemented. Both refining of requirements and using the modular body armor approach require high-level coordination because of the potential risk. Improving testing requires approval from the Office of the Director, Operational Test and Evaluation (DOT&E), and developing better materials requires funding and time.

With regard to estimated weight reductions, greater increases in reduction may be possible if some of the approaches are considered synergistically. For example, a larger weight loss should be achieved if the benefits derived from reduced requirements are combined with the benefits gained from improved testing coupled with modular configurations.

Conclusions

The conclusions of this study are as follows:

- Today, no "silver bullet" material solution exists that will greatly reduce body armor weight.
- Some means (mainly nonmaterial) are available that can reduce body armor weight.
- A combination of material and nonmaterial approaches to lighten body armor will result in greater weight reductions.
- Synergy of modular concepts may lead to greater weight reduction (e.g., integration of hard and soft body armor designs).
- Further reductions in weight will require a significant investment of money and time.

A 10 percent reduction in weight appears to be about the most that is realistic in the short term if overall protection is to remain constant. Even this small increment will be quite difficult to achieve, however. A longer-term solution to reducing body armor weight likely involves the development and integration of new materials. However, the technology is currently too immature to make reliable estimates about the weight and protective effectiveness of new materials.

There are some nonmaterial solutions available that can result in a greater than 20 percent weight reduction. For example, with modular body armor configurations, a 45 percent reduction results when BAPL 2 is selected instead of BAPL 5.[1] The problem is that the choice of the appropriate BAPL is a difficult decision. Also, a large inventory of body armor vests and plates must always be available to provide the various plates and vests in all sizes to forward to combat areas.

A combination of material and nonmaterial approaches should result in greater weight reduction. For example, if the plates are over-designed for the threat, then the requirements and testing procedures could be changed, resulting in thinner and lighter-weight plates.

A synergy of modular concepts may also lead to greater weight reduction. Soft and hard body armor should be developed and procured as one item. Today's practice is to simply add hard plate inserts to a soft vest, but a systems approach would design a single body armor concept that optimized the characteristics of the two components.

Further reductions in weight will require a significant investment of money and time. Changes to the plate design could reduce the plate weight. For example, variable-thickness plates could be constructed that provide greater protection over the chest portion of the torso than over the abdomen portion. However, variable-thickness plates would involve changing the manufacturing process and the testing procedures.

Answers to the eight issues specifically raised by Section 125 are presented in the main body of the document.

Recommendations

As a result of our examination of the issues associated with reducing the weight of body armor, we propose four top-level recommendations:

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1 BAPL 5 includes an improved outer tactical vest with front, back, and side plates, while BAPL 2 uses a plate carrier without the side plates.

- First, development of significantly lighter, next-generation body armor using advanced technology materials will require more research, development, test, and evaluation (RDT&E) funding, though we have not attempted to quantify that requirement. The various RDT&E program elements also need to be better coordinated, and the various service efforts should be mutually supporting.
- Second, the threat level requirement should be consistent with the threat environment being encountered today and anticipated in the future.
- Third, the requirements-development process needs to be reviewed to ensure that coordination among the relevant stakeholder offices is continuous as requirements are developed. Making optimal trade-offs between protection, weight, ergonomic impact, and cost requires ongoing interaction among the user representative, the technical community, and the resource providers, from the start of requirements assessment to the publication of the requirements document.
- Fourth, performance—including weight—should be included as a contract award selection criterion when awarding production contracts for body armor. Currently, products that meet the threshold criteria are selected solely on a cost basis by the Defense Logistics Agency, so prospective producers have no incentive to improve body armor performance beyond the threshold.

We also propose five specific recommendations:

- Exceptions should be made to the Berry and Kissell Amendments, which limit the design and manufacturing of soft body armor intended for U.S. service members to American and Canadian producers. If offshore sources offer improved body armor solutions, they should not be denied to our service members.
- The 1977 Prather study that provided a preliminary correlation of mortality and backface deformation on soft body armor should be updated by conducting new research using today's body armor (soft and hard). New data will help improve requirements generation and make testing more realistic.
- Field commanders may be reluctant to utilize a BAPL lower than the maximum without some sort of decision aid tool to back up their assessment. The development of the Operational Requirements-based Casualty Assessment (ORCA)/Modular UNIX-based Vulnerability Estimation (MUVES) model should be continued and used to help develop a decision aid that field commanders can use to make BAPL decisions.
- A comprehensive trauma data collection and analysis process should be established to better inform researchers, developers and decisionmakers.
- Finally, research should be conducted to better understand how body armor weight degrades soldier combat performance. There is a trade between individual protection and individual—and unit—effectiveness. That trade space is not well understood today, so making assessments concerning developmental requirements and about BAPL during operations is currently difficult.

Acknowledgments

We are grateful to Scott Fish, Army Chief Scientist, and Carolyn Nash, Office of the Assistant Secretary of the Army for Acquisition, Logistics and Technology, for their guidance and interest in the study. We also wish to thank the following Army personnel for providing important information on body armor: Gary Pesano and Chris Perritt, PM Soldier Protection and Individual Equipment; James Zheng and Karl Masters, PEO Soldier; Michael Codega, Natick Soldier Research, Development, and Engineering Center; John Beatty, Patrick Gillich, Lisa Roach, and Steve Taulbee, Army Research Laboratory; and COL Jeff Holt and Lindsey Yowell, Aberdeen Test Center. Thanks also go to Judah Goldwasser, Defense Advanced Research Projects Agency; Christopher Moosmann, Office of the Director, Operational Test and Evaluation; Lt Col Kevin Reilly and Major Billy Short, U.S. Marine Corps; and Col Richard Converse, James Boisselle, and Richard Dunnigan, U.S. Special Operations Command. We thank the following body armor vendors for providing valuable technical information: Mack Thorn, BAE Systems; Marc King, Ceradyne; Tim Haen, Coorstek; Ron Egres, DuPont; and Lori Wagner, Honeywell.

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Abbreviations

AEI	Armament Enhancement Initiative
AoA	Analysis of Alternatives
ARL/SLAD	Army Research Laboratory, Survivability and Lethality Analysis Directorate
ATC	Aberdeen Test Center
ATM	Anthropomorphic Test Module
BAA	Broad Agency Announcement
BAPL	Body Armor Protection Level
BAST	Board on Army Science and Technology
BFD	backface deformation
CBA	Capabilities Base Assessment
CBRN	chemical, biological, radiological, nuclear
CDD	Capability Development Document
CNT	carbon nanotube
CSS VSAT	Combat Service Support Very Small Aperture Transmission
DARPA	Defense Advanced Research Projects Agency
DAS	Defense Acquisition System
DLA	Defense Logistics Agency
DoD	Department of Defense
DOT&E	Office of the Director, Operational Test and Evaluation
ESAPI	enhanced small arms protection insert
ESBI	enhanced side body insert
FAT	first article test
ICD	Initial Capabilities Document
IED	improvised explosive device

IOTV	improved outer tactical vest
JCIDS	Joint Capabilities Integration Development System
JROC	Joint Requirements Oversight Council
JTAPIC	Joint Trauma Analysis and Prevention of Injury in Combat program
LAT	lot acceptance test
LSAPI	light small arms protection insert
MAIS	Maximum Abbreviated Injury Scale
MDO	Materiel Development Decision
METT-C	Mission, Enemy, Time, Terrain, Civilians
MOPP	Mission Oriented Protective Posture
MUVES	Modular UNIX-based Vulnerability Estimation Suite
NRAC	Naval Research Advisory Committee
O&M	operations and maintenance
ORCA	Operational Requirements-based Casualty Assessment
PEO	program executive office, program executive officer
PM	program manager
POR	program of record
PPBES	Planning, Programming, Budgeting, and Execution System
PPE	personal protective equipment
R&D	research and development
RDECOM	U.S. Army Research, Development and Engineering Command
RDT&E	research, development, test, and evaluation
SAPI	small arms protection insert
SOCOM	U.S. Special Operations Command
SOFSA	Special Operations Forces Support Activity
STF	shear thickening fluid
TRADOC	U.S. Army Training and Doctrine Command
UHMWPE	ultra-high-molecular-weight polyethylene
XSAPI	X-small arms protection insert

CHAPTER ONE

Introduction

This report documents RAND Arroyo Center support to the U.S. Army in responding to Section 125 of the National Defense Authorization Act for Fiscal Year 2011 (P.L. 111-383). The research on lightening body armor was performed over a two-and-a-half-month period. The cutoff date of the research phase was mid-June 2011. The research consisted of literature reviews, interviews, independent analyses, and a synthesis of the study findings. Besides providing general conclusions, the specific questions that are raised in Section 125 are addressed. Both top-level and specific recommendations are made regarding lightening body armor.

Purpose of the Study

Congressional concerns about efforts across the department of Defense (DoD) to develop lighter-weight body armor resulted in Section 125 of the National Defense Authorization Act for Fiscal Year 2011. Section 125 directs DoD to contract with a federally funded research and development center to study how the DoD effort to lighten body armor could be improved. Congress directed that the study be performed by an independent, objective analysis team composed of analysts that understood both advanced material technologies and combat operations. The RAND Arroyo Center was selected by the U.S. Army to perform this study.

The basis of congressional concern is a perception by some in Congress that DoD has been slow in developing and deploying lighter-weight body armor. Congress believes that this may be due to the research and development (R&D)/procurement approach that the Army currently has in place to develop and introduce lighter-weight body armor.

The body armor study requirements listed in Section 125 are as follows:

1. Assess the effectiveness of the process used by the Secretary [of Defense] to identify and examine the requirements for lighter-weight body armor systems.
2. Determine ways in which the Secretary may more effectively address the research, development, and procurement requirements regarding reducing the weight of body armor.

The research reported in this document addresses these two study requirements.

Section 125 also states that the study must address the following issues:

1. the requirement for lighter weight body armor and personal protective equipment and the ability of the Secretary [of Defense] to meet such requirements
2. innovative design ideas for more modular body armor that allow for scalable protective levels for various missions and threats

3. the need for research, development, and acquisition funding dedicated specifically for reducing the weight of body armor
4. the efficiency and effectiveness of current body armor funding procedures and processes
5. industry concerns, capabilities, and willingness to invest in the development and production of lightweight body armor initiatives
6. barriers preventing the development of lighter weight body armor (including such barriers with respect to technical, institutional, or financial problems)
7. changes to procedures or policy with respect to lightweight body armor
8. other areas of concern not previously addressed by equipping boards, body armor producers, or program managers.

These issues fall under four general areas:

- requirements for lighter-weight body armor and the ability to meet them
- innovative design ideas and required funding for reducing body armor weight
- barriers/concerns that prevent the development of lighter-weight body armor
- efficiency/effectiveness in current funding procedures and processes and required changes to procedures and policy.

To perform the required analyses in the allotted time period, the study focused on the most important aspects of body armor protection—ballistic threats and torso protection.

Study Caveats

The study has two major caveats. First, the study's focus is on soldier protection from ballistic threats; nonballistic threats are only indirectly considered. Ballistic threats include small arms fire and fragmenting munitions from improvised explosive devices (IEDs), land mines, and indirect fires. IEDs are very effective fragmenting munitions. They have killed more troops in Afghanistan than any other weapon type. Soft body armor is designed to protect against shrapnel from fragmenting munitions.[1]

Second, our research focus is limited to torso armor, since most of the body armor weight is in protecting the torso area of the body. Since technological advances are being made in other soldier personal protective equipment areas, there was less need to investigate them. For example, the advanced technology helmet currently being developed is made from ultra-high-molecular-weight polyethylene and weighs slightly less than the current Kevlar helmet. Face protection masks and groin protection are also being developed. In contrast to these lighter-weight components, protection of the torso area is provided using soft body armor vests with ceramic plate inserts, which are effective but heavy.

[1] Soft armor was designed to provide fragmentation protection and was based on an early study of land mines and grenades. Although soft and hard armor were not designed to protect against the IED threat, they do have a certain protection level against shrapnel from IEDs or other threats. Hard armor provides much higher fragmentation (shrapnel) protection than soft armor. However, the overpressure from an IED blast is a different story. Recent research shows that soft armor has almost no effect on overpressure, but hard armor has some level of overpressure reduction, i.e., provides some degree of protection if the overpressure is the cause of the injury. The primary concern for torso protection against a blast has been lung injury. However, it appears that lung injury caused by blast overpressure is rare in the field, according to the medical community's injury analysis. (Dr. James Q. Zheng, PEO Soldier, private communication, June 29, 2011.)

Research Approach

The analysis was performed following a three-prong research approach that consisted of literature reviews, interviews, and independent analyses.

Literature Review

The literature reviews consist of assessments by the Army Audit Agency, the Government Accountability Office (GAO), the DoD Inspector General (DoD IG), and the Board on Army Science and Technology (BAST) of the National Academies. These assessments concentrated on testing issues.

Interviews

Both on-site and telephone interviews were conducted with 18 organizations that are involved with body armor development and procurement. These included eight separate Army organizations: Program Executive Office (PEO) Soldier (Haymarket), PEO Soldier/Program Management (PM) Soldier Protection and Individual Equipment, PEO Contracting Office, the U.S. Army Training and Doctrine Command (TRADOC) Maneuver Center of Excellence, the Army Research Laboratory (ARL), the Natick Soldier Research, Development, and Engineering (RD&E) Center, the ARL Survivability/Lethality Analysis Directorate, and the Aberdeen Test Center (ATC). In addition, we interviewed two Navy/Marine Corps organizations, the Office of Naval Research (ONR) and Marine Corps Systems Command (MCSC) (Infantry Combat Equipment, Armor and Load Bearing Team [PM-ICE]); U.S. Special Operations Command (SOCOM) and the Defense Advanced Research Projects Agency (DARPA); the Office of the Director, Operational Test and Evaluation (DOT&E); two civilian testing facilities, Chesapeake testing and HP White; and five body armor vendors (Ceradyne, Coorstek, BAE Systems, Honeywell, and DuPont). The vendors represent two plate manufacturers, two soft armor providers, and one integrator.

Independent Analyses

Our independent analyses concentrated on future materials for soft and hard body armor. Performance potential and cost were investigated.

Organization of This Document

The organization of this report is as follows. In Chapter Two, we present background on some issues associated with body armor operations, effectiveness, and requirements. In Chapter Three, we describe four approaches to lightening body armor and assess each. In Chapter Four, we provide an overall comparison of the four approaches, present our general conclusions, and specifically address each of the eight congressionally raised issues. Finally, in Chapter Five we provide both top-level and specific recommendations.

CHAPTER TWO

Background

The purpose of this chapter is to set the stage for our analysis, in Chapter Three, of four approaches to lightening body armor. In this chapter we discuss three related points, each of which highlights an issue that affects body armor.

Soldier Combat Load Is Daunting

The first point is that soldier combat load is very heavy and detrimental to combat performance. Body armor is a significant contributor to this overall load.

Average Combat Loads for Soldiers and Marines

Dismounted soldiers fighting in Afghanistan carry very heavy loads relative to their body weight. Figure 2.1 shows such a soldier, carrying a full combat load. Table 2.1 shows the combat loads for three duty positions under three operational load conditions—average fighting load, average approach march load, and average emergency approach load.

The average fighting load includes the following items: bayonet, weapon, clothing, helmet, body armor, load-bearing equipment, and a reduced load of ammunition. The average approach march load includes the fighting load items and, in addition, a basic load of ammunition, a small assault pack, and a lightly loaded rucksack or poncho roll. The average emergency approach march load includes the approach march load and, in addition, a much larger

Table 2.1
Average Combat Loads for Army Soldiers in Afghanistan, 2003

	Average Fighting Load		Average Approach March Load		Average Emergency Approach Load	
Duty Position	Weight (pounds)	Percentage of Body Weight	Weight (pounds)	Percentage of Body Weight	Weight (pounds)	Percentage of Body Weight
Rifleman	63	36	96	55	127	71
Squad automatic rifleman	79	45	111	63	140	80
60mm mortar gunner	64	38	108	64	143	87

SOURCE: Task Force Devil Combined Arms Assessment Team (Devil CAAT), "The Modern Warrior's Combat Load: Dismounted Operations in Afghanistan, April–May 2003," Ft. Leavenworth, Kan.: U.S. Army Center for Army Lessons Learned, 2003.

NOTES: 48–72-hour average mission duration. Load includes body armor with two small arms protection insert (SAPI) plates and no neck or crotch guards (17.5 lb).

Figure 2.1
An Army Soldier Carrying a Full Combat Load

SOURCE: Task Force Devil Combined Arms Assessment Team (Devil CAAT), "The Modern Warrior's Combat Load: Dismounted Operations in Afghanistan, April–May 2003," Ft. Leavenworth, Kan.: U.S. Army Center for Army Lessons Learned, 2003.
RAND *TR1136-2.1*

rucksack. All three combat loads include a body-worn hydration system that can contain up to three liters of water and weigh up to nine pounds full.

Soldiers in Afghanistan in 2003 wore lighter-weight body armor. Their protection consisted of a vest with two small arms protective insert (SAPI) plates. Today, Army body armor is generally heavier, as much as twice that worn in 2003.

It has, of course, been long recognized that too-heavy combat loads can reduce soldier effectiveness. In 2001, GEN Eric Shinseki, Army Chief of Staff, expressed a goal that the combat load of the individual soldier serving in the Future Force was not to exceed 50 pounds. This goal was to be reached by 2010, but that has not been realized.

Marines carry combat loads that are similar in weight to what Army soldiers carry. Figure 2.2 shows the actual assault loads for six Marine Corps duty positions on combat patrols. The data are from a 2007 Naval Research Advisory Committee (NRAC) panel study that addressed the issue of lightening the combat load.[1] The NRAC study also recommended a maximum assault load of 50 pounds.

Load Impacts Performance

The U.S. Marine Corps is adamant that heavy loads are detrimental to combat performance. Numerous anecdotes abound that comment on the consequences of carrying heavy loads. As a Marine Corps officer put it in November 2006, "We were ordered to wear everything everywhere in the mountains all the time . . . even if you were in great shape, you couldn't keep up

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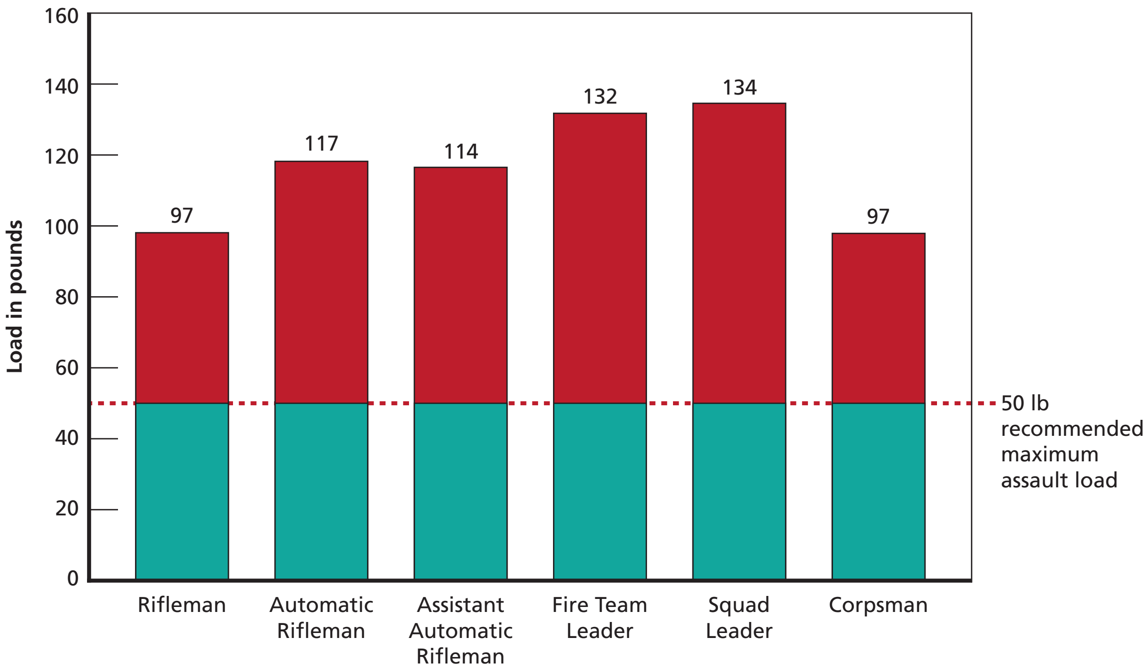
1 Naval Research Advisory Committee, "Lightening the Load," briefing to Honorable Delores M. Etter, Assistant Secretary of the Navy for Research, Development and Acquisition, September 2007.

Figure 2.2
Individual Combat Loads for Marines, by Position



SOURCE: Naval Research Advisory Committee, "Lightening the Load," briefing to Honorable Delores M. Etter, Assistant Secretary of the Navy for Research, Development and Acquisition, September 2007.
RAND *TR1136-2.2*

with the enemy."[2] Or, as it was phrased at the August 2005 Marine Corps Noncommissioned Officer Lessons Learned Conference, "Ounces equal pounds and pounds equal pain."

The NRAC study proposed several material solutions to help reduce the load. They include lighter body armor, caseless ammunition, lightweight weapons, integrated optics, advanced batteries, and overall systems integration. Of all of the material solutions, the NRAC felt that the biggest savings could be gained from lightening body armor. The NRAC also investigated other means of lightening a squad's load. They included offloading certain items and transferring the load via manned/unmanned ground and aviation vehicles, enhancing human performance through tactics and training, and using a systems engineering approach to reducing weight.

It is interesting to note that the loads carried by various infantry units through history experienced a sharp increase starting in World War I. Up until then (from the Greek Hoplites and Roman Legions through the Civil War), the loads were in the 40-pound range.[3] By the time World War II started, the combat loads had increased to 85 pounds and have remained at this level or higher ever since.

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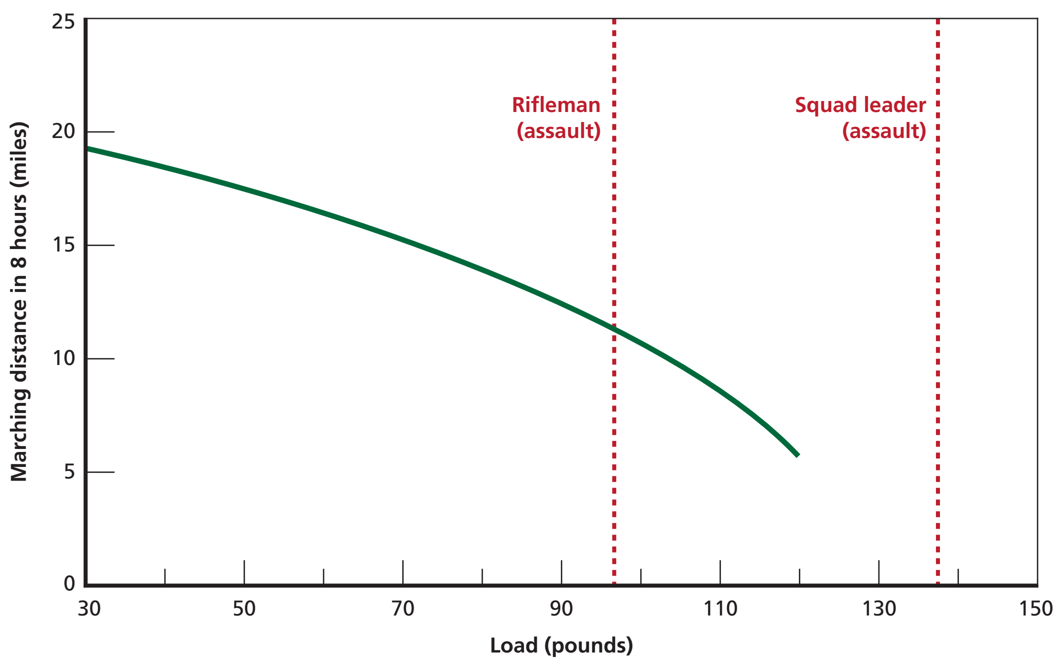
2 Naval Research Advisory Committee, 2007, p. 43.

3 Joseph Knapik, "Physiological, Biomechanical and Medical Aspects of Soldier Load Carriage," meeting on Soldier Mobility, Kingston, Canada, RTO MP-056, June 2000.

Heavy loads can severely impact a soldier or marine's combat performance.[4] Figure 2.3 illustrates the effect of combat load on a marine's performance.[5] (Similar results apply to a soldier on a dismounted patrol.) For a rifleman, increasing his load from 50 pounds (goal) to 95 pounds (actual today) reduces the marching distance that a soldier/marine can traverse in eight hours by 35 percent (from approximately 17 to 11 miles). (However, as shown in Figure 2.3 by the dotted vertical lines, the model did not cover the greater weight carried by a squad leader.) The decrease in distance covered over time is also likely to be impacted by the terrain in which the soldiers or marines are operating and the weather conditions where the operations are taking place.

Other studies have been performed that consider different performance measures for soldiers and marines. One such study looked into the physical performance of soldiers who were wearing personal protective equipment (PPE). In this study of 21 military personnel, the researchers observed a performance reduction during the functional field tests, along with dec-

Figure 2.3
Performance Decreases as Combat Load Increases



SOURCE: Unpublished findings from a 1988 Army study by R. F. Goldman.
NOTE: The conditions are for a weight of 171 pounds, a walking surface composed of dirt, a 1 percent grade, and a work level of 350 Kcal/hour.
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[4] Long-term injuries are also being blamed on excessive combat loads. A newspaper report found that the number of soldiers medically retired from the Army with at least one musculoskeletal condition increased nearly tenfold from 2003 to 2009, according to Army statistics. The heavy combat loads contributed to a rising number of Afghanistan and Iraq war veterans retiring with degenerative arthritis, cervical strains, spinal injuries, and other musculoskeletal injuries. (Associated Press, "Combat Soldiers Are Carrying Too Much Weight," *Seattle Times*, February 13, 2011.)

[5] The curve shown in this figure is based on an Army study developed using R. F. Goldman's unpublished findings on metabolic energy cost modeling. A current review of metabolic cost models is summarized by Albert Adams III, "Effects of Extremity Armor on Metabolic Cost and Gait Biomechanics," thesis, Worchester Polytechnic Institute and U.S. Army Natick Soldier Research, Development and Engineering Center, 2010.

rements in cardiovascular performance, balance, and strength when wearing PPE (a system of Kevlar front and back plates and an unlined combat helmet).[6]

In another study the physical work performance, energy cost, and physiological fatigue experienced by military personnel were examined when wearing body armor. In this study of 34 military personnel, the findings indicate a significant metabolic cost with increased exercise while wearing body armor.[7]

In a third study, the physiological, biomechanical, and performance of 11 enlisted Army men not wearing armor, an armor vest, or a vest plus extremity armor were tested on separate days in walking, running, and three maximal-effort tasks. The maximal-effort tasks were five continuous 30-m rushes, five minutes of repetitive lifting of a 20.5-kg box, and an obstacle course run. The study demonstrated that performance on maximal efforts was poorer when extremity armor was worn than when armor was not used or only the armor vest was worn; that the use of extremity armor increases the users' metabolic cost while performing soldier tasks and alters gait biomechanics compared with no armor or an armor vest alone; and that there were significant changes in walking and running biomechanics when extremity armor was worn compared with not wearing armor.[8]

Body Armor Weight Contributes to the Overall Load

Today's body armor is heavy and represents a large amount of the combat load that a soldier carries. The weight of a full-up torso body armor set ranges from approximately 27 to 38 pounds, for small to extra-large sizes, respectively.[9] (In our analysis, we have used a medium size body armor set [32 pounds] in our weight comparisons, realizing that the conclusions based on it also effectively apply to the other sizes.)

A 10 percent reduction in body armor weight is not that easy to achieve.[10] Moreover, as we discuss below, a 10 percent reduction lessens the soldier's total combat load by only a few pounds. While every pound that is shaved off the soldier's load is important, three to four pounds only make a small dent in the effort to reach the 50-pound goal.[11]

The challenge is what material and nonmaterial solutions are available to achieve larger weight reductions.

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6 M. DeMaio, J. Onate, D. Swain, S. Ringleb, S. Morrison, and D. Naiak, "Physical Performance Decrements in Military Personnel Wearing Personal Protective Equipment (PPE)," poster presentation at the Symposium on Human Performance Enhancement for NATO Military Operations in Sofia, Bulgaria, October 5–7, 2009.

7 Richard Ricciardi, Patricia A. Deuster, and Laura A. Talbot, "Metabolic Demands of Body Armor on Physical Performance in Simulated Conditions," *Military Medicine,* September 1, 2008, pp. 817–824.

8 Leif Hasselquist, Carolyn K. Bensel, Brian Corner, Karen N. Gregorczyk, and Jeffrey M. Schiffman, "Understanding the Physiological, Biomechanical, and Performance Effects of Body Armor Use," *26th Army Science Conference Proceedings*, Orlando, Fla.: Natick Soldier Research, Development and Engineering Center, December 2008.

9 Weights are for a torso set consisting of an improved outer tactical vest (IOTV) with deltoid protector and enhanced small arms protection insert/enhanced side body insert (ESAPI/ESBI) ceramic plates.

10 "For plates, a 10 percent weight reduction for ESAPI continues to challenge industry" (Natick Soldier RD&E Center body armor overview briefing, March 31, 2011).

11 The doctrinal fighting load is actually 48 pounds, not 50 (BG[P] Peter Fuller, Program Executive Officer Soldier, testimony before the House Armed Services Committee, March 17, 2011).

Current Body Armor Is Effective

The second point is that today's body armor appears to be effective. U.S. Rep. Roscoe Bartlett (R-MD) has stated:

> Our troops and their families should be reassured to know that to date there hasn't been a single fatality from a failure of currently issued body armor. Specifically, the Army and officials from the Joint Trauma Analysis and Prevention of Injury in Combat (JTAPIC) program found that there hasn't been any penetrations of body armor or a fatality associated with what the currently issued body armor was designed to stop.[12]

Statements like this suggest that there have not been any penetrations of body armor or fatalities associated with the threat that currently issued body armor was designed to stop. Indeed, we were not able to uncover any evidence that current body armor is not effective against the threat for which it is designed. However, while data are routinely collected on soldier injuries and deaths, there may be missing information. For instance, plates are often not returned or associated with the stricken soldiers or bodies. This means that the database may be missing critical information.

In 2004, a theater trauma system was in place for collecting data on trauma patients and implementation of a performance improvement program. Data collected on trauma patients included demographics, mechanism of injury, physiology, diagnostics, treatments, and outcomes, and this information was placed into the Joint Theater Trauma Registry (JTTR). Data collection in the trauma registry continues today, as does the performance improvement for trauma care across the continuum. The injury data collected along with body armor worn is given to the Joint Trauma Analysis and Prevention of Injury in Combat (JTAPIC) program for analysis. If adequate data have been collected, the effectiveness of today's body armor could be quantified. However, we were unsuccessful in obtaining casualty data from the JTAPIC program.

While today's body armor appears to be effective, it may also be that the body armor is over-designed for the threats that our soldiers and marines are facing in Afghanistan. (JTAPIC data should also be able to help answer this question.) While casualty data are reported in specific case studies, further analysis of the complete data is needed to better understand the following:

1. Does body armor protect against ballistic threats?
2. What is killing our soldiers? Concussive blast? Shock? Headshots through the helmet? Headshots in noncovered areas? Neck or throat shots? Torso shots through the soft armor? Torso shots through the plates? Exsanguinations because of a severed limb or artery not covered by body armor? Such information is needed.
3. There should be a report on every penetrating wound. Who has these reports and what is done with the data?

We recommend that JTAPIC identify and analyze casualty trends and circulate its findings among the body armor research community.

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[12] "Congressman Roscoe Bartlett Reassures Troops and Their Families That They Are Protected by Effective Body Armor in Iraq and Afghanistan," press release, January 6, 2011.

Body Armor Must Be Capable of Handling Multiple Ballistic Round Penetrations and Limiting Backface Deformation

The third point is that today's body armor has two key requirements: It must be capable of handling multiple ballistic round penetrations and limiting backface deformation (BFD). Both requirements are stringent to meet.

The purchase description for personal armor protective inserts states that the ceramic plates must be able to stop three rounds spaced in a well-defined shot pattern.[13] In addition to meeting this penetration requirement against different ballistic rounds, body armor plates must also meet other conditions (temperature extreme, fluid resistance, altitude test, fungus test, etc.). In order to satisfy all of these requirements, the ceramic plates are necessarily heavy.

The ability to limit BFD is another stringent requirement. BFD is a surrogate measure of blunt force trauma. Clay is used as the backing in tests where BFD is measured as the depth of the crater created after bullet impact.[14] Based on 1977 research findings by Prather, Swann and Hawkins, 44 mm indentation has been accepted by the Army as the maximum accepted depth.[15,16]

These test requirements are for the current Army X-small arms protection insert (XSAPI) test procedures. Other test requirements have been used that vary slightly with plate type and time.[17]

Both the multiple ballistic round penetration and the maximum backface deformation requirements force the vendors to produce heavy ceramic plates with adequate backing material.

Basis for the Two Requirements

The requirement that body armor be able to handle multiple ballistic round penetration is based on a conservative decision approach and the desire to protect against this type of attack in-theater.

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13 Purchase Description, "Personal Army X Small Arms Protective Insert," FQ/PD 07-03B, August 25, 2010.

14 Convention dictates that the crater in clay resulting from a ballistic test be called backface deformation (BFD), but it is more accurately described as backface signature (BFS). The degree of plate deformation (BFD) in a ballistic test is actually less than the resulting crater (BFS). (J. P. F. Broos and M. J. van der Jagt-Deutekom, "What Does the Indent in Plastilina Mean?" Personal Armour Systems Symposium (PASS), Quebec City, Canada, September 13–17, 2010.)

15 R. Prather, C. Swann, and C. Hawkins, *Backface Signatures of Soft Body Armors ad the Associated Trauma Effects*, Aberdeen Proving Ground, Md.: Chemical Systems Laboratory, November 1977.

16 Current DOT&E requirements state that "60 plates are to be tested in nine environments, under ambient conditions and by shot order" (*Standard for Lot Acceptance Testing of Hard Body Armor*, memorandum 2 July 2010). The 60-plate design is replicated for each threat. The DOT&E standard does not specify the specific threats for testing. For any threat, the following is required to successfully pass the first article test (FAT):

- For the first shot, the 90 percent lower confidence bound for the probability of no complete penetration is greater than or equal to 0.9.
- For the second shot, the 90 percent lower confidence bound for the probability of no complete penetration is greater than or equal to 0.7.
- For the first shot, with 90 percent confidence the 90 percent upper tolerance limit for the BFD is less than 44.0 mm.
- For the second shot, with 90 percent confidence the 80 percent upper tolerance limit for the BFD is less than 44.0 mm.

17 For example, the March 2010 ESAPI PD used a point system to determine first article test (FAT) failures based on first and second shot penetrations and BFD greater than 44 mm, while the December 2009 XSAPI PD also used a point system but a 43 mm BFD requirement with a pass/fail criteria that differed by threat type.

The BFD requirement is based on 1977 study by Prather, Swann, and Hawkins, commissioned by the National Institute for Law Enforcement and Criminal Justice of the Law Enforcement Assistance Administration. The purpose of the study was to develop a simple, readily available backing material for use in characterizing both the penetration and deformation effects of ballistic impacts on soft body armor and relate this deformation to the injury potential of nonpenetrating ballistic impacts.

Prior to the study, 20 percent gelatin had been used as a backing material for the study of ballistic impacts on soft body armor materials. However, a major limitation of gelatin is the near total recovery of any deformation that may occur. The only way to analyze deformations in gelatin is through the use of high-speed photographic techniques. The Prather study was able to establish that Roma Plastilina 1 clay was a second option that could be used to correlate clay deformation to injury and tissue deformation. Because the clay exhibited very little recovery, a readily available impact cavity could be used for BFD measurements.

To establish the acceptable BFD, a model was formulated using experimental data sets obtained from tests on anesthetized animals, for which physical characteristics of the impacting projectile was known.[18] Based on the model and tests done with the clay, Prather, Swann, and Hawkins concluded that "A depth of deformation greater than 50 mm is associated with the probability of lethality of approximately 15%."[19] This is shown in Figure 2.4. They also wrote, "However, the available data is limited and hence no solid conclusions can be drawn as yet regarding the effect of deformation depth."[20] Regardless, the limited data were used as the basis for mathematical modeling that predicted that a BFD of 44 mm or less would ensure a probability of lethality no greater than 10 percent.

The 44 mm standard should be corrected in three ways. First, this standard was established in tests with soft body armor. Second, the model created to equate clay BFD to tissue deformation and lethality was based on limited data. Third, injury data from human ballistic impacts were not readily available in the past, and the BFD standard that was set has not been validated. The 44 mm standard should be reevaluated using the human ballistic impact and injury data from the conflicts in Afghanistan and Iraq that PEO Soldier and JTTR collect and submit to JTAPIC.

Summary

These three related issues—the goal of reducing average combat loads, the effectiveness of current combat armor, and the requirements that body armor must meet—inform our assessments of the approaches to improving body armor. In Chapter Three, we discuss four such approaches.

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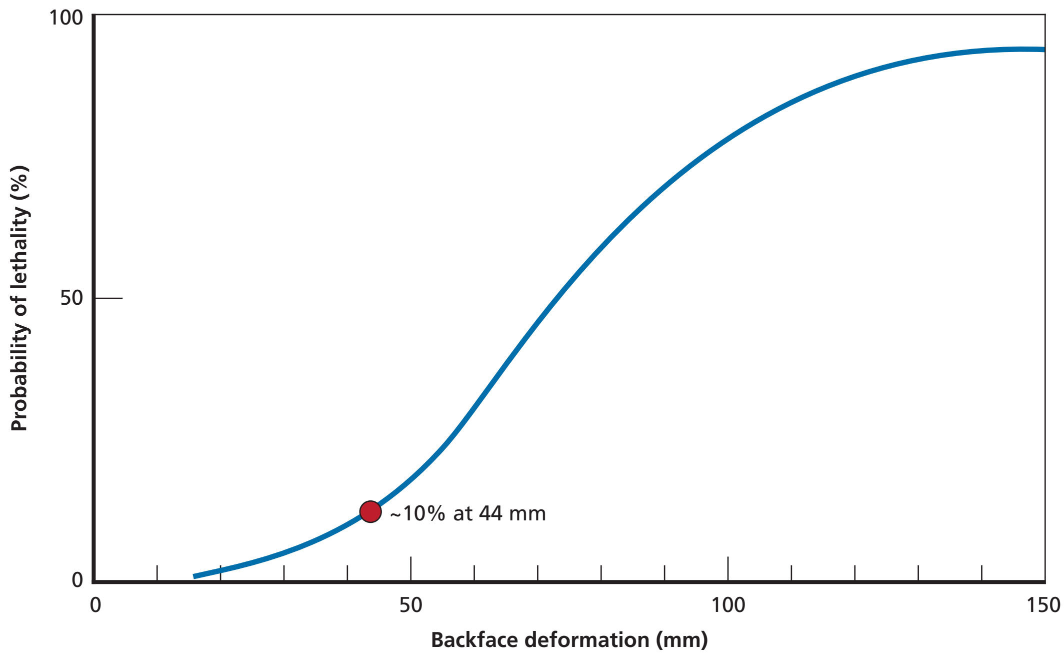
[18] Data for three animal species were used in the analysis. The database consisted of 30 live cohorts each, of goats, swine, and dogs (Victor Clare, James Lewis, Alexander Mickiewicz, and Larry Sturdivan, "Blunt Trauma Data Collection," Edgewood Arsenal, Aberdeen Proving Ground, EB-TR-75016, May 1975). In a related study, goats were used that wore lightweight soft body armor (Biophysics Division 1-A, "Backface Signature Study Using Armored Goats," internal report, undated).

[19] Prather, Swann, and Hawkins, 1977, p. 10.

[20] Prather, Swann, and Hawkins, 1977, p. 10.

Figure 2.4
Probability of Lethality as a Function of Backface Deformation



SOURCE: R. Prather, C. Swann, and C. Hawkins, *Backface Signatures of Soft Body Armors and the Associated Trauma Effects*, Aberdeen Proving Ground, Md.: Chemical Systems Laboratory, November 1977.
RAND *TR1136-2.4*

CHAPTER THREE

Four Approaches to Lightening Body Armor

In this chapter, we discuss four approaches for lightening body armor and assess their potential. Both material and nonmaterial means are considered.

The first candidate approach to lightening body armor is reassessing the threat and refining requirements. As we mentioned in Chapter Two, a big driver in designing body armor that will provide adequate protection is the threat that the body armor will encounter. If the plates are over-designed relative to the threat, then weight can be shaved off the ceramic plates, and this reduction will permit the vendors to introduce more innovation into their plate designs.

A second approach involves using modular body armor configurations to better match the protection to the expected threat. As we will discuss later, this approach is already available but comes with great risks.

A third approach is to improve the Army's testing procedures to eliminate any excess variation in the tests, such as by reformulating the clay so that it can be used at ambient temperatures. Such changes may reduce the need to over-design the plates in order to pass the tests, and thus potentially allow for lighter-weight body armor to be constructed.

A fourth approach is to develop new soft and hard body armor materials that are inherently stronger relative to their weight. This development will most likely require more research, development, test, and evaluation (RDT&E) funding and may require changes in the procurement process that is used today to procure body armor as a commodity item.

Refining Requirements

We start our analysis by looking at refining requirements as an approach to lighten body armor. Because the details of threats that the body armor must be effective against are classified, our discussion of requirements is limited. We use unidentified threats in place of the classified threats; the relationship between threat and requirements can still be explained using the notional threats.

Assessing Threats

Eight threats have been devised that cover a range of calibers and projectile types for ESAPI and XSAPI ceramic inserts. These are labeled as follows:

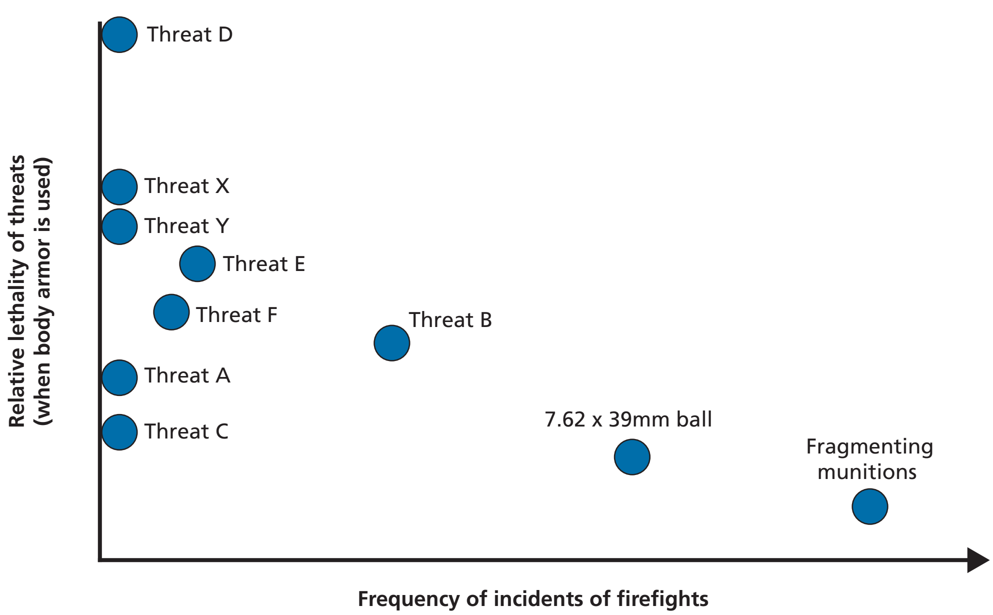
- Threat A
- Threat B
- Threat C

- Threat D—the most stressing type, and the former test standard
- Threat E—less stressing than Threat D, and the current test standard
- Threat F
- Threat X
- Threat Y

The current line of ceramic inserts has been designed to protect against a worst-case scenario—conflict with a nation-state that is well funded and considered a near-peer military competitor to the United States. While it is important to prepare for a large-scale conflict against a sophisticated adversary, current ceramic inserts are over-designed for the threat posed by the Taliban, al Qaeda militants, and other belligerents currently opposing U.S. forces in Afghanistan. Over-design means a heavier plate than necessary to counter the threat. The military, realizing this, has stepped back from using the most stressing round available (Threat D) and is now using Threat E as the primary standard, a move that will likely result in ceramic insert weight reductions.

Figure 3.1 shows the protection level of current body armor against the threats occurring in Afghanistan and Iraq. The x-axis shows the frequency of employment of the threat rounds in the current theater of operations. The y-axis shows the relative lethality of a given threat round against ceramic-plate protected body armor. Soft body armor alone protects against shrapnel from fragmenting munitions, and the addition of SAPI will successfully defend against AK-47 ball ammunition. The ESAPI and XSAPI plates were designed to protect against armor-piercing ammunition, which is rarely employed by our current enemy. The new testing standard, Threat E, is more likely to be encountered in the battlefield (although still rare) than Threat D, which is a test round not available on the world market.

Figure 3.1
Effectiveness of Body Armor Against Different Threat Types



RAND *TR1136-3.1*

Tailoring Body Armor as a Means to Lighten Body Armor

While a certain amount of armor overmatch is desired, extensive overmatch has operational costs, such as excess weight and bulk that reduces the maneuverability and mobility of the wearer.[1] One relatively simple weight reduction technique is to allow commanders to tailor body armor to match the current threat level in theater. For example, the threat in Afghanistan today is primarily fragmenting munitions, 7.62mm x 39 ball bullets, and 7.62mm x 54R ball bullets. Current body armor provides excessive overmatch against those threats, and its weight could likely be reduced if designed to the threat. If the threat were to increase (to armor-piercing rounds, for example), the level of body armor protection could increase as well.[2]

The military tends to be risk-adverse and requires its plates to withstand trauma in worst-case scenarios (muzzle velocity against armor-piercing bullets) instead of the data-supported threat. And leaders are understandably reluctant to make the decision to scale down threat requirements, lest they be blamed for a soldier death or injury due to projectile-armor overmatch. Yet, due to several large purchases over the past decade, the military now has a wide variety of ceramic plates in inventory (SAPI, ESAPI, XSAPI, and soon light SAPI [LSAPI]) designed to protect against a variety of threats. With this inventory, commanders could tailor body armor levels based on the current threat, without additional cost to the Army.

Using Modular Configurations

Next, we look at modular configurations as an approach to lighten body armor and discuss the merits and risks of this approach.

Combat conditions can vary greatly based on the mission, the threat, and the environmental conditions, such as elevation. Accordingly, field commanders must be able to adjust body armor to minimize the detrimental effects of weight and heat without unduly sacrificing protection. To enable these adjustments, requirements developers have established language to specify how body armor must be configurable for the range of combat conditions.

Requirements developers have parsed the configurability of body armor into three aspects: modularity, tailorability, and scalability. The draft Soldier Protection System Capability Development Document defines these terms as follows:[3]

1. Modular: Made up of separate modules that can be rearranged, replaced, combined, or interchanged easily.

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1 There are no data that we could uncover that address how current body armor affects lethality and injury to U.S. forces, despite the decade-long natural experiment in Iraq and Afghanistan. Nor does there seem to be data from operational testing to assess the effects that degraded individual performance due to the weight and bulk of the body has on operational effectiveness. These kinds of data are critical for developing better requirements.

2 Changing test requirements to meet current battlefield threats would indeed lessen plate weight (SAPI is lighter than ESAPI, which is lighter than XSAPI). However, we must have body armor in the inventory to protect against possible worst-case threats, in the event that our enemies begin to use armor-piercing ammunition. Therefore, we cannot simply lessen the threat requirements. Instead, the recommendations come down on the side of modularity of body armor that can be tailored to protect against the current threat, but could also be modified quickly if the threat increased.

3 Capability Development Document (CDD) for Soldier Protection System Increment I, ACAT: III, draft version 1.0, 10 December 2010.

2. Tailorable: The ability to adapt body armor to make it suitable for a particular duty position, mission, etc.
3. Scalable: Describes protection levels that can be upgraded or downgraded to meet a specific threat.

An example of modularity is adopting plate carriers in lieu of the improved outer tactical vest (IOTV) for dismounted operations at high elevation. An example of tailorability is allowing a static, relatively vulnerable gate guard to wear groin, throat, and shoulder armor protection but also to remove them when more movement is required. An example of a scalable system is the Body Armor Protection Levels (BAPLs) described later in this chapter.

These aspects of modularity, tailorability, and scalability are somewhat similar in nature; the key takeaway is that they allow a commander to reduce the body armor weight of his soldiers when appropriate for the threat environment.

Examples of Modular Configurations

Like helmets and uniforms, ceramic plates (and the vests that carry them) come in multiple sizes to fit the wearer properly. Different plates are available, as well, to defeat varying levels of threat. The larger the plate, and the more lethal the threat against which the plate is designed to defend, the more the plate weighs. Special Operations Forces use a suite of plates that includes a swimmer plate design that allows greater range of arm motion. Figures 3.2 shows the ECLiPSE Solar family of plates that were designed by the Special Operations Equipment Advanced Requirements (SPEAR) under the Body Armor/Load Carriage System (BALCS) program (BAE Systems, 2012).[4]

Figure 3.3 gives a sense of the variety of configurations and body armor components that are available. When soft armor alternatives, whether vest or plate carrier, are used in conjunction with plates of varying protection level, as well as supplemental protection for the groin, throat, and shoulders, the number of possible configurations becomes quite large. While Figure 3.3 shows a group of armor systems, they are only examples and are not currently used as such by any particular DoD component.

Coverage Versus Weight

While the correlation between body armor weight and the amount of the body covered by soft armor should be intuitive, Figure 3.4 shows the estimated linear relationship between coverage and weight. In this figure, the body armor weight includes the weight of the inserts. What is important is the slope of the curve, which is 1.1 pounds of weight per square foot of soft ballistic coverage. Soft armor protects against small-caliber handgun rounds, shotgun blasts, and fragmenting munitions, such as hand grenades. Covering more of the body with soft armor results in greater protection from these threats, but at the cost of increased weight.

Figure 3.4 does not explicitly portray thermal load, which is also correlated to area coverage and is an increasing concern of requirements developers.

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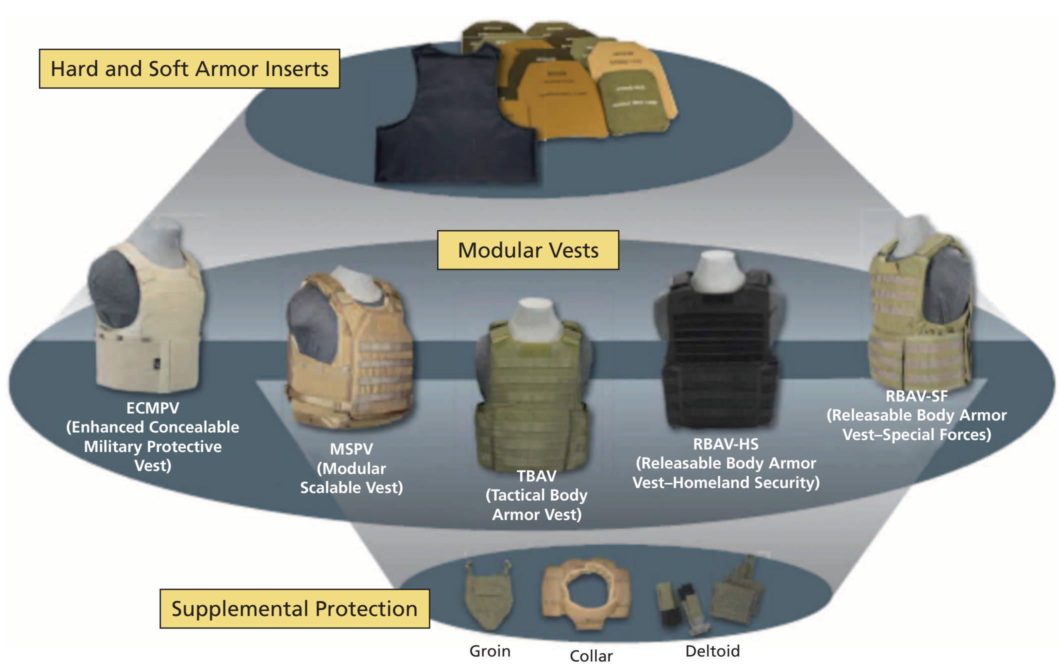
4 The reason special operations forces are able to operate with more modular designs and mission-specific plates is because established mission profiles allow small unit commanders to accept higher levels of risk. This is different from the Army and Marine Corps forces, who do not have access to the same quality of intelligence for their missions and tend to wear full protection because they must expect the unexpected. (COL [Ret.] Luigi E. Biever, former Director, Joint Staff Support Services and Joint Staff Inspector General, private communication, June 10, 2011.)

Figure 3.2
An Example of a Suite of Body Armor Plates

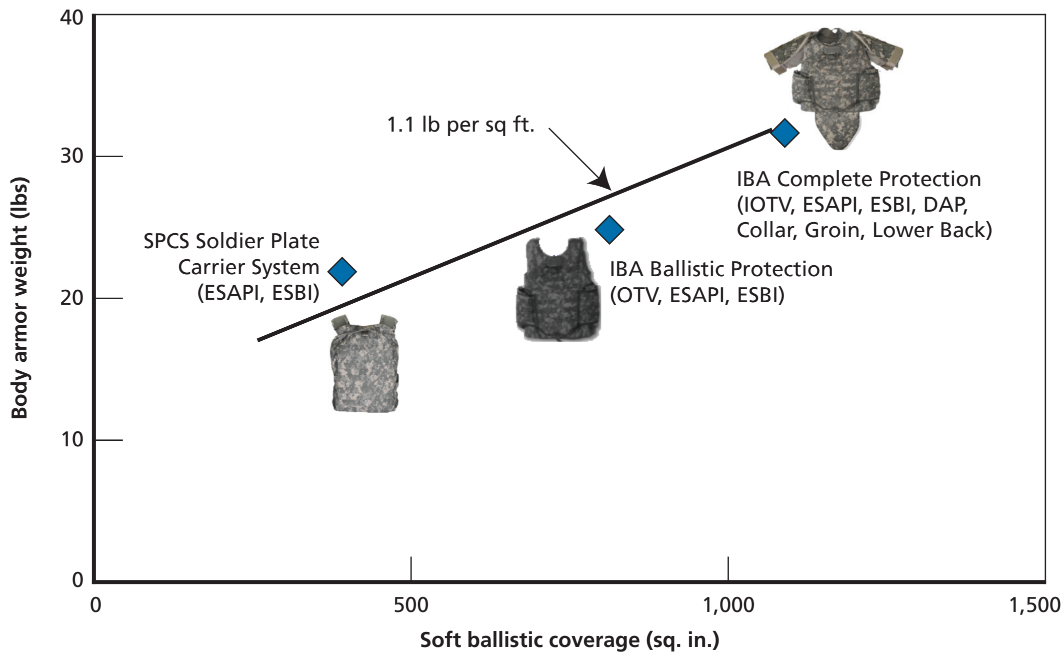
SOURCE: BAE Systems, 2012.
RAND *TR1136-3.2*

Figure 3.3
Example Components for Modular Body Armor Configurations



SOURCE: BAE Systems, 2012.
RAND *TR1136-3.3*

Figure 3.4
Body Armor Weight Increases as Coverage Increases



SOURCE: Based on data provided by PM Soldier Protection and Individual Equipment, private communication, April 2011.
NOTES: The figure shows values for size medium body armor with all plates. SPCS = Soldier Plate Carry System; IBA = Interceptor Body Armor; DAP = deltoid and axillary protectors; OTV = outer tactical vest; IOTV = improved outer tactical vest.
RAND *TR1136-3.4*

Body Armor Protection Levels

Both the Army and the Marine Corps have established BAPLs, which are described in Table 3.1. Like Mission Oriented Protective Posture (MOPP) levels for CBRN (chemical, biological, radiological, or nuclear) threats, BAPLs standardize commanders' options in determining the appropriate amount of protective equipment based on METT-C (mission, enemy, time, terrain, civilians) considerations. While the Army's six BAPL levels distinguish between two soft body options (IOTV and plate carrier) to account for the different protection and weight associated with each, the Marine Corps' four-level system does not direct which soft body option is used in a given BAPL.

Note that the weights shown are for X-threat protection, which is the heaviest. Weight is lower when ESAPI and LSAPI plates are worn. Asymmetric plate configurations, e.g., XSAPI on the front and ESAPI in the rear, could also reduce weight. These additional configurations—whether the ability to adjust both plate protection levels or the ability to wear mismatched plates—would necessitate additional BAPL designations.

The Army Research Laboratory's Survivability and Lethality Analysis Directorate (ARL/SLAD) performs survivability/lethality/vulnerability analyses using a software package called Modular UNIX-based Vulnerability Estimation Suite (MUVES). By integrating the Operational Requirement-based Casualty Assessment (ORCA) into MUVES, the SLAD team has developed a new approach to personnel survivability and casualty assessment.

Table 3.1
Body Armor Protection Levels

Body Armor Protection Level	Body Armor Configuration	Weight of Army BAPL (pounds)[a]
Army Level 0 (USMC BAPL 0)	No body armor worn	0
Army Level 1 (USMC BAPL 1)	Vest or plate carrier with soft armor only	6/10.5
Army Level 2 (USMC BAPL 2)	Plate carrier with front and back plates	18
Army Level 3 (USMC BAPL 3)	Plate carrier with front, back, and side plates	23
Army Level 4 (USMC BAPL 2)	IOTV with front and back plates	28
Army Level 5 (USMC BAPL 3)	IOTV with front, back, and side plates	32

SOURCES: Draft Capability Development Document (CDD) for Soldier Protection System, Appendix F, December 10, 2010; "Memorandum on Establishment of Body Armor Protection Levels," LTG Michael A. Vane, Director, Army Capabilities Integration Center, March 8, 2011.

[a] For medium size with XSAPI/XSBI plates. Weight varies depending on plate model, type, size.

The ORCA computer model uses over 40 inputs to characterize operational casualties. While this software is useful in performing casualty analysis, using it on the battlefield is currently impractical. However, there is a need for some decision aid tool that can help field commanders decide what level of body armor protection their units should wear. SLAD has already characterized the results of the ORCA/MUVES computer model using a Maximum Abbreviated Injury Scale (MAIS). There are six MAIS score levels. A score of 4 or above indicates that a soldier is no longer able to function on the battlefield. With further research, it should be possible to create a decision support tool that allows the field commander on the ground to input a military occupation specialty (MOS) or some other general classification at the battalion level or higher, a threat level, and the percentage of injuries that should not exceed a MAIS score of 3. Based on this information, the decision support tool could provide an appropriate BAPL for the field commander to use.

Using Modular Configurations as a Means to Lighten Body Armor

Configuring body armor to meet METT-C conditions is the single largest way to reduce weight and the only solution that is immediately available. The weight of the Army's BAPL 2—plate carrier with front and back plates—for example, is less than half (45 percent) the weight of the most protective and heaviest configuration, BAPL 5. This approach, however, poses two challenges.

First, commanders must be able to accurately identify METT-C conditions. While it is relatively easy to anticipate whether a mission will traverse difficult terrain at high elevation, it may be more difficult to consistently and accurately predict the type of munitions the enemy will use. Considering how decisions by the chain of command at the battles of Wanat and Kamdesh have been scrutinized and second-guessed, commanders may be reluctant to accept risk by assigning lower BAPLs.

Ideally, commanders should understand how increases in ballistic protection can actually result in added risk and reduced performance because the additional weight and thermal load reduce mobility and cognitive ability. Additional research is needed to identify the trade space between survivability and performance for a given mission profile, but there may be value in creating a decision aid to facilitate leaders' BAPL decisionmaking now and adjusting the decision aid's parameters as the trade space is better understood. ARL/SLAD has indicated that it could develop such a tool for commanders (an application for smart phone, for example) in a relatively short time frame and relatively little cost.

A second challenge is that, in order to achieve the most fully configurable suite of body armor options, the services would need multiple plates (both ESAPI and XSAPI, for example) and both a vest and plate carrier option. This creates a logistical challenge, in that a larger inventory of body armor must be maintained and available in the forward areas of combat theaters, where body armor is most needed. For the Army and Marine Corps, an expansion of current fielding plans could raise costs significantly—first in procurement, then in sustainment, which, given ceramic plates' susceptibility to cracking, could be considerable.[5] The services could limit costs by fielding multiple plates only to those personnel who are likely to perform missions where load is operationally relevant and METT-C conditions will vary.

Improving Testing

We will now look at testing as an approach to lighten body armor.

Literature Review

Body armor testing has received a great amount of scrutiny in the past. Some of this scrutiny is attributable to statements made by Pinnacle Manufacturing regarding its Dragon Skin armor, which failed government testing despite the manufacturer's claims. Some of the scrutiny was attributable to a lack of standardization across the services, as well as limited failures within the Army to properly execute its testing protocols. In the course of exploring how testing might play a role in body armor weight, we determined that the ballistic testing community, led by DOT&E, has largely addressed all the issues about which auditing agencies expressed concern.

Limited opportunities remain, however, to further improve testing by decreasing remaining areas of test variability. Reducing variability is important because it ensures the fairest test for the vendor and may provide an additional, though limited, means to reduce ceramic plate weight.

We examined the following documents in our literature review:

U.S. Government Accountability Office:

- *Independent Expert Assessment of Army Body Armor Results and Procedures Needed Before Fielding*, GAO-120-119, October 2009
- *Defense Logistics: Army and Marine Corps' Individual Body Armor Systems Issues*, GAO-07-662R, April 2007
- *Actions Needed to Improve the Availability of Critical Items During Current and Future Operations*, GAO-05-275, April 2005

[5] SOCOM does not use BAPL because SPEAR offers a variety of body armor configurations that are matched to the SOF mission profiles.

Army:

- *Body Armor Requirements*, Army Audit Agency Report No. A-2009-0130-FFD, June 8, 2009
- *Body Armor Testing: Program Executive Office, Soldier*, Army Audit Agency Report No. A-2009-0086-ALA, March 30, 2009

Department of Defense Inspector General:

- *Ballistic Testing and Product Quality Surveillance for the Interceptor Body Armor—Vest Components Need Improvement*, DoD IG Report No. D-2011-030, January 3, 2011
- *DoD Testing Requirements for Body Armor*, DoD IG Report No. D-2009-047, January 29, 2009
- *DoD Procurement Policy for Body Armor*, DoD IG Report No. D-2008-067, March 31, 2008

National Academies (BAST):

- *Testing of Body Armor Materials for Use by the U.S. Army, Phase II: Letter Report*, April 2010
- *Testing of Body Armor Materials for Use by the U.S. Army, Phase I: Letter Report*, December 2009
- *Testing of Body Armor Materials for Use by the U.S. Army, Phase III: Letter Report*, forthcoming.[6]

We understand from DOT&E that new reports on ballistic testing from the DoD Office of the Inspector General and Army Auditing Agency are forthcoming.

Our Findings Regarding Current Testing

There is a consensus within the body armor community that the early problems in test execution have been addressed. Multiple agencies described initial Operation Iraqi Freedom/Operaton Enduring Freedom body armor testing as understaffed and struggling to meet an urgent and previously unforeseen need. Because the services had not anticipated a requirement for every soldier and marine to have body armor, they were forced to procure and issue it on a scale that was, for a time, overwhelming. This lack of preparedness extended to body armor testing, for which each service used its own standards and protocols. After several auditing and oversight agencies discovered a range of testing shortfalls, DOT&E developed and implemented statistically principled ballistic testing protocol that all services must follow. Improvements include centralizing the first article test (FAT) at ATC and ensuring that lot acceptance tests (LATs) at third-party labs meet ATC standards. The result is significantly improved testing—a testament to the commitment of the testing community, the value of auditing agencies, or both.

While testing procedures have vastly improved, more work remains to be done. First, as the BAST Phase II report first reported, it is difficult to distinguish between variability in the armor and variability in the test; however, when a plate fails, the government attributes

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6 Phase III of the National Academies series on "Testing of Body Armor Materials for Use by the U.S. Army" is expected in the coming months. This phase of the report will address alternatives to clay in ballistic testing.

the cause to variability in the test. Because of this, manufacturers have an incentive to over-design their plates as a hedge against test failure. One vendor estimates that over-design due to the test's variability amounts to about one-half pound.

Second, we observe that the test represents a worst-case scenario. While we applaud the Army's adoption of a more operationally relevant testing round by moving from Threat D to Threat E, the circumstances under which it is fired—at muzzle velocity and zero-degree obliquity—are not representative of operational conditions.[7]

Our Findings Regarding Future Testing

Although using clay (as a human body substitute) as the backing material for measuring BFD is an imperfect test medium, there are currently no suitable cost-effective alternatives. Alternatives to clay include ballistic gelatin, anthropomorphic test modules (ATMs) and microcrystalline wax. The FBI uses ballistic gelatin for its testing. While gelatin and clay can be used as surrogates for the human body, gelatin has the advantage of translucence to allow observation of the test event. It also has some notable disadvantages. First, because of gelatin's limited shelf life, full-scale testing operations that use gelatin for routine testing, such as lot acceptance tests (LATs), would require more preparation than clay does. This additional work could necessitate expanding facilities leading to the test range, slow test throughput, or a combination of the two. Second, while clay can be resculpted should a penetration occur, gelatin blocks must be replaced after a penetration.

ATMs offer a similar drawback in that, should a penetration occur, the recording device is likely to be damaged. Also, research and development of an underbody blast ATM is expected to total $80–$100 million.[8] Absent another cost estimate, we conclude the cost to develop a ballistic testing ATM may be similar. Microcrystalline wax structures, according to the BAST Phase II report, show promise but, because their rheological properties are not fully understood, would require additional research before adoption as a ballistic test medium.

Transitioning to a new medium would require establishing not only a relationship between the test medium and human injury probabilities, but also to existing test data. If DoD leaves clay in favor of a new medium, testers will want to understand not only the relationship between the new medium and the human body, but also between the new medium and clay. Without understanding how the new medium relates to clay, there will be no ability to compare test results with the vast catalog of previous test results. If DoD, as the BAST Phase II report recommends as an option, adopts a mid-term replacement to clay while a long-term replacement is developed, these linkage requirements would double.

Large investments to improve testing may not be warranted. If the next ten years of body armor development and procurement were expected to be like the last ten years—with DoD spending billions of dollars for the most protective and lightest body armor that can be

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7 A major concern is that rounds that strike the body armor during testing are at muzzle velocity and zero-degree obliquity. While this ensures that any threat encountered by the plates can be defeated, it is unlikely that an enemy combatant would be able to fire a weapon at the close quarters required to ensure the body armor is hit by a round at muzzle velocity. Additionally, the round used for testing is not what is currently seen on the battlefield but instead a round with a greater probability of defeating the body armor. While this also ensures that any threat seen on the battlefield will likely fail to penetrate the armor, it further incentivizes body armor manufacturers to over-design body armor plates to ensure that they pass testing.

8 Mr. Richard Sayre, Director, Live Fire Test & Evaluation, Office of the Director, Operational Test and Evaluation, private communication, April 18, 2011.

produced—or if improving testing protocols were a way to significantly (for example, by more than 20 percent) reduce body armor weight, then large investments to improve testing might well be warranted. But neither of these conditions exists.

Testing as a Means to Lighten Body Armor

DoD should continue its efforts to reduce variability in testing. Two ongoing initiatives—reformulating clay for ambient temperature and testing with clay at ambient temperature—are representative of good, relatively low-cost efforts that should reduce variability and result in a fairer test. And, as funding allows, other efforts should be pursued. In particular, DoD should consider implementation of the BAST Phase II report recommendations. We do not, however, believe that DoD would be well served by a high-cost strategy to replace clay.

Improving Materials

Finally, we will look at different material solutions as an approach to lightening body armor. Development and incorporation of advanced technology materials into soft and hard body armor may require changes to the procurement process and the need for additional R&D funding.

Materials Used in Today's Body Armor

Kevlar, a DuPont product, and Twaron, a brand name of Teijin Aramid, are commonly used as the fibers in the soft armor vests. Kevlar has been around since the mid-1960s and Twaron since the mid-1970s. Both are para-aramid fibers. They are very strong, with a high tensile strength, and are thermally stable and chemical resistant. The soft body armor vendors use different weaves and patterns to maximize the fibers' effectiveness.

Hard body armor plates are generally made from boron carbide or, sometimes, silicon carbide. Boron carbide (B_4C) is the lightest ceramic material (2.5 g/cm^3) as well as the hardest (second only to diamond) for durability, and it has a high hardness (3,200 Kg/mm^2). Other physical characteristics of B_4C include erosion resistance and high modulus.[9] Silicon carbide (SiC) has a higher density (3.15 g/cm^3) and a lower hardness (2,300 Kg/mm^2). Both boron carbide and silicon carbide plates can be manufactured using either a hot press or sintering process.[10]

The ceramic plates are covered by a layer of polymer composite to help pass the required drop test and prevent shattering of the plates when struck by a projectile. The plates are wrapped in a tightly woven ballistic fabric for protection from the environment and for increased back-face protection.

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[9] The density of a material is defined as its mass per unit volume. Hardness is defined as the resistance of a material to localized deformation. The modulus of a material is a measure of its stiffness, and determines the degree to which it will deflect when a given load is imposed on a given shape.

[10] Sintering involves the coalescence of individual ceramic particles, usually in a powder form, into a continuous solid phase at a high temperature without actually melting the ceramic material.

Potential Future Body Armor Materials

Modern body armor consists of a hard plate, typically ceramic, backed by a soft woven fabric. The weight of body armor might be reduced by improving the materials used for the plate and/or the fabric.

Fabric Materials. Soft armor, made up of ballistic fabrics, dissipates energy through stress waves in the fabric, fiber deformation, and inter-fiber friction as the fibers slide against each other. Improvements in all three mechanisms are possible via future materials. Para-aramid composite fabrics, such as Twaron and Kevlar, are particularly useful due to their fiber-deformation characteristics.

Another promising para-aramid is Rusar, a fiber developed in Russia for ballistic protection. Rusar has some characteristics that are superior to Kevlar and Twaron fibers.[11] While the fiber is manufactured by a process that is similar to the traditional method used for aramid fibers, we were told that the ingredients cost roughly five times that of other para-aramids and, because the acids require special equipment, the process costs about fifteen times what a typical para-aramid process costs.[12] If this fiber proves to be superior to Kevlar and Twaron, the U.S. may be prohibited from importing it because the Berry and Kissell Amendments give preference to domestically produced textile materials including those used in body armor.

Ultra-high-molecular-weight polyethylene (UHMWPE) fibers, such as Spectra and Technora, have improved ballistic performance. However, UHMWPE fibers have a tendency to degrade under various environmental conditions, including exposure to moisture, UV light, and gamma radiation. Yarns of carbon nanotubes (CNT) have excellent material properties. CNT production is still very expensive and their environmental performance is unknown.

Plate Materials. The role of the ceramic plate is to deform and decelerate the projectile and distribute the impact over a larger area of the soft armor backing. The pertinent material parameters are high hardness and toughness. The hardness deflects and deforms the projectile while the toughness determines the amount of energy absorbed prior to material failure. In general, ceramics are low density, high hardness materials that perform this role. Typical ceramic material used include: aluminum oxide (Al_2O_3), boron carbide (B_4C), titanium diboride (TiB_2), or silicon carbide (SiC). The material challenge for these ceramics is to increase the fracture toughness, while maintaining sufficient hardness. In an effort to balance toughness and hardness, variants of SiC-N and SiC-B are potentially useful.

Several different alternative armor constructions with potential for weight reductions have also been the subject of research and testing, including laminated composites containing ceramics and polymers.[13]

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11 I. V. Slugin, G. B. Sklyarova, A. I. Kashirin. L. V. Tkacheva, and S. V. Komissarov, "Rusar Microfilament Yarn for Ballistic Protection, *Fiber Chemistry*, Vol. 38, No. 1, 2006, pp. 22–24.

12 Dr. Ron Egres, DuPont, private communication, June 3, 2011.

13 For example, armor designs, such as the gradient composite armor system, composed of layers of ceramic particles/epoxy composite, have been found to out-perform solid ceramic tiles in terms of weight, ballistic limit, and flexibility. (N. V. David, X. L. Gao, and J. Z. Zheng, "Ballistic Resistant Body Armor: Contemporary and Prospective Materials and Related Protection Mechanisms," *Applied Mechanics Reviews*, Vol. 62, No. 5, September 2009, p. 8.)

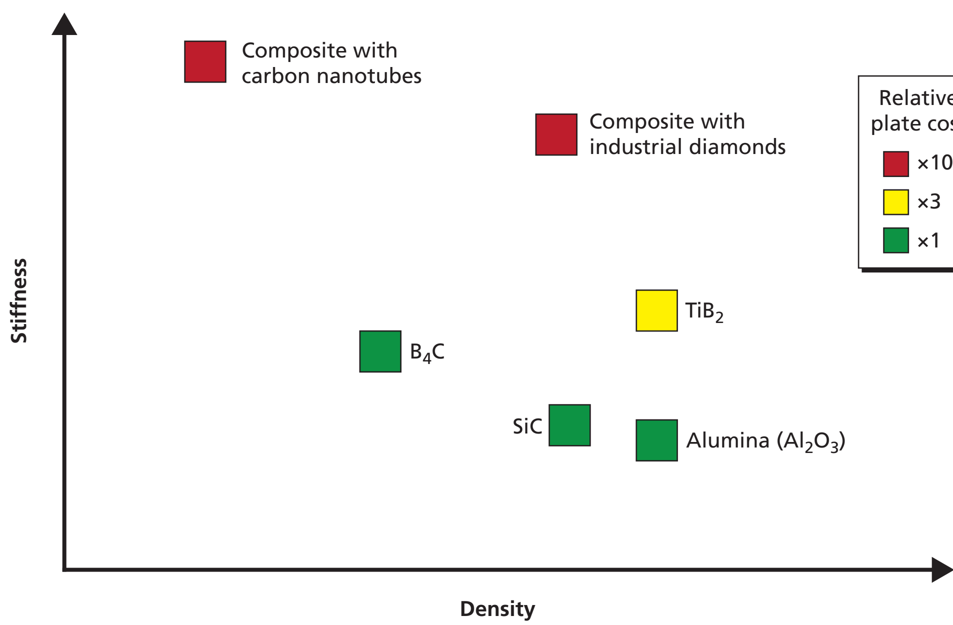
Improving Hard Armor Materials

It is unlikely that there will be further easy or inexpensive improvements to the hard plate component of the body armor system from the introduction of new monolithic ceramic materials.[14] Instead, potential improvements will have to occur via the introduction of high-performance, but expensive, materials such as CNT or industrial diamonds in discrete amounts or through advanced ceramic processing methods. These methods add cost and may complicate final testing due to increased performance variation.

Figure 3.5 displays one important material parameter, stiffness, of current and potential hard plate materials as a function of density. Stiffness is usually indicative of a material's hardness.[15] However, a general caveat to Figure 3.5 is that static material properties are not always indicative of ballistic performance; shock loading under ballistic conditions is an open research question. The color-coding in Figure 3.5 designates the relative cost of the new materials relative to today's ceramic plates.

The bulk ceramics currently in use (SiC, Al_2O_3, and B_4C) have reasonable performance, particularly for a low-density material. There are no readily available ceramics that show markedly improved performance and density characteristics. To improve performance, high-performance materials, such as CNT, may be required. CNTs are a lightweight, flexible, and high-strength material with exceptional energy absorption capability. Due to their high cost, which makes it unlikely that CNTs will ever be competitive with bulk ceramics, CNTs could be incorporated into a composite structure in the ceramic plate. Initial results of CNT incorporation into SiC and Al_2O_3 showed improved toughness and hardness. An improvement in

Figure 3.5
Stiffness of Current and Potential Hard Plate Materials as a Function of Density



RAND *TR1136-3.5*

[14] A comprehensive review of materials technology for armor is currently being prepared by the National Academies' National Materials Advisory Board (NMAB) project, titled "Opportunities in Protection Materials Science and Technology for Future Army Applications."

[15] Hardness is difficult to measure, so stiffness is often used as a proxy in materials science.

toughness of 94 percent was observed with an addition of 4 percent (by volume) of CNTs in Al_2O_3.[16]

The inclusion of micro- or nano-particles in a composite system is often used to modify performance. For example, ceramic particles are included in epoxies used to make tennis rackets or golf club shafts to increase the strength. In the case of hard armor applications, the particles are not added to improve strength but to improve toughness. CNTs have exceptional energy absorbing properties that improve the toughness of the total system. CNTs are particularly impressive because they also have excellent hardness.

Improving body armor material requires a system-level perspective. Ceramic hard plate improvements are likely to be the result of advanced processing, incorporation of composite structures, or the use of high performance additives. The ballistic response of the ceramic plate is related to the toughness and hardness of the material. Fracture toughness is a measure of the resistance to crack propagation in the material. Materials with higher toughness absorb more energy prior to fracture, minimizing the projectile's penetration depth. Ceramic processing techniques, such as using additives (e.g., aluminum into SiC) during the sintering process, can alter the material's structure and improve toughness. The chemical composition of the ceramic can also be modified in the underlying material structure. For example, SiC-N incorporates silicon nitride phases with the bulk SiC material. SiC-N has demonstrated toughness values twice that of standard SiC, though with a loss of hardness. Optimizing ceramic performance will require ballistic testing to assess appropriate hardness and toughness parameters for SiC-N or other ceramics.

The performance of ceramics can also be improved through the use of thin coatings to the front face of the plate. TiB_2 thin films are used as hard coatings in many industrial applications. One could imagine a SiC-N plate with its improved toughness, coated with a thin TiB_2 layer to compensate for its decreased hardness. Any assessment of these complicated plates must account for the overall weight and cost. Complex ceramic processing and the application of a thin, hard coating are likely to be expensive.

It should be noted that increasing the toughness and/or hardness does not necessarily improve ballistic performance. The impact of a high velocity projectile on a ceramic plate results in an extremely high strain-rate condition. The strength, hardness, and toughness of a material under these extreme conditions are not uniformly predicted by standard material properties. For example, the toughness of SiC was significantly improved through the addition of an aluminum-boron-carbon sintering agent. However, the improved toughness did not improve ballistic performance. In any assessment of new material systems, the ballistic performance in the actual body armor system must be evaluated.

Improving Soft Armor Materials

Improvements of soft armor focus on improving either the inter-yarn friction or individual fiber performance. Inter-yarn friction can be enhanced via the use of shear-thickening fluid (STF). STF is a liquid filled with particles whose viscosity increases with the strain rate. Thus, when impacted by a projectile, the suspended particles begin to aggregate. This aggregation increases the viscosity of the fluid. As a result, soft armor enhanced with STF behaves like rigid armor when impacted by the projectile. These improvements come at the expense of weight.

[16] David, Gao, and Zheng, 2009.

Incorporating STF will necessitate fewer fabric layers to maintain comparable areal densities. As is the case with ceramic hard plates, final assessment requires ballistic testing of the entire body armor system. Inter-yard friction can also be increased via a coating of the individual yarns. Examples of yarn coatings include natural rubber and resins. As is the case with STF, these coatings improve performance with a weight penalty.

Individual fiber strength can be increased by fabricating them out of CNTs or by reinforcing standard fiber materials with CNTs. Single CNT fibers exhibit strength and hardness values approximately three times that of state-of-the-art Kevlar fibers. Nylon fibers reinforced with CNTs show toughness and hardness increases of 150–300 percent. These reinforced fibers are then woven into yarn and subsequently into fabrics used to make soft armor.

As is the case with incorporating CNTs into ceramic plates, the cost of integrating CNTs into soft armor is currently very high and is unlikely to decrease to the levels of current soft armor fibers.

How to Best Develop the Next Generation of Body Armor: Acquisition Program of Record Versus Commodity Procurement

As our previous discussion has pointed out, the development of lighter-weight body armor will require significant RDT&E and time, because the general consensus within the hard body armor community is that simple improvements to monolithic ceramic performance have already been made. Any further mass efficiencies may come from improvements in processing. While a replacement for ceramic plates is being investigated, candidate replacement materials tend to be technologically immature, and their projected cost is comparatively very expensive. Similarly, advances in soft body armor materials are being studied. In both cases, improvements to hard and soft body armor will require a large amount of RDT&E funds and will take several years.[17] Up until now, there has been a steady progression in body armor improvements, from SAPI to ESAPI to XSAPI and now to LSAPI plates, and from military flak and Personal Armor for Ground Troops (PASGT) vests to vest enhancements to OTV to IOTV to SPCS. While impressive, the improvements have been essentially evolutionary, not revolutionary. The designs have been driven by a changing threat and the availability of new technology (whether it is a new technique for weaving fibers or stronger yet lighter plates).

A question that is often raised is: Should the development of the next generation of soft and hard body armor be conducted under an acquisition program of record, or can it remain under a commodity procurement process in the same way that the previous body armor improvements have been developed, even though significant improvements to the next-generation body armor will be much more difficult to achieve? We will next discuss the similarities and differences between an acquisition program of record and a commodity procurement approach, which are summarized in Table 3.2. From this discussion, we will give the pros and cons of continuing with the commodity procurement approach.

A commodity procurement usually involves the purchase of readily available items, such as clothing. Operations and maintenance (O&M) funds are used to purchase the commodity. RDT&E funds are available for technology development, and a program executive officer (PEO)/program manager (PM) manages the development process. After the commodity has

[17] The Army is seeking to develop the capability to design, optimize, and fabricate lightweight protection material systems exhibiting revolutionary performance. A new Collaborative Research Alliance (CRA) focused on Materials in Extreme Dynamic Environments (MEDE) has been established.

Table 3.2
Comparison of Commodity Procurement Versus Hypothetical Program of Record Acquisition

Process		Commodity Procurement	Program of Record Acquisition
Requirements		Combatant commands submit statement of need to TRADOC Maneuver Center of Excellence (MCoE), which conducts cost-benefit analysis to prepare courses of action	JCIDS requirements generation process used
Development	Concept	PEO Soldier, with U.S. Army Research, Development and Engineering Command's (RDECOM's) input, synthesizes the research and experiments on materials, design, and manufacturing	Essentially same approach
	Design and prototype	PEO Soldier prepares specifications in conjunction with TRADOC Maneuver Center of Excellence (MCoE)	Essentially same approach
	Testing	ATC performs all FAT and most LAT testing (some outsourcing of LAT is permitted) with ATC oversight	Essentially same approach
Acquisition		RDECOM Contracting Center issues Broad Agency Announcement (BAA) and Solicitation, Offer and Award, and awards contract for body armor as a commodity; DLA contracts for sustainment buys	Body Armor PM created under PEO to oversee program from initial material solution analysis through sustainment phase; multiyear funding

been developed, tested, and given limited fielding, the Defense Logistics Agency (DLA) contracts to vendors to purchase the commodity. Usually the contract selection criterion is lowest cost. While this process is reasonable for buying clothing, however, it appears less suited for procuring high-technology body armor.

An acquisition program of record follows a lengthy, carefully managed, and highly scrutinized process that is composed of three overlapping components—the Joint Capabilities Integration and Development System (JCIDS, the requirements system), the Planning, Programming, Budgeting, and Execution System (PPBES, the resource allocation or budgeting system), and the Defense Acquisition System (DAS, the acquisition system). For example, the JCIDS is a rigorous requirements generation process.[18] The Capabilities Based Assessment (CBA) is part of the JCIDS process that analyzes the military's capability needs and gaps and recommends both material and nonmaterial ways to address the gaps. If, as a result of a CBA, a material solution (such as lightweight body armor) is considered, an Initial Capabilities Document (ICD) is prepared. The Joint Requirements Oversight Council (JROC), the organization responsible for identifying and prioritizing warfighter requirements, must approve the ICD. If the JROC approves the pursuit of a material solution, the program enters the DAS.

The DAS, as well as the PPBES process, involve equally lengthy and rigorous processes with decision points, milestone reviews, and entrance criteria. For example, to enter the DAS, a program must first pass a Materiel Development Decision (MDD) review. An Analysis of Alternatives (AoA) is then conducted and a Technology Development Strategy (TDS) is created. During this phase, technologies are developed, matured, and tested. In addition, a Capability Development Document (CDD) and Reliability, Availability, and Maintainability

[18] The source for the following is Moshe Schwartz, *Defense Acquisitions: How DoD Acquires Weapons System and Recent Efforts to Reform the Process*, Washington, D.C.: Congressional Research Service, RL34026, April 2010.

(RAM) strategy are developed. The technology development phase is complete when, among other things, an affordable program is identified.

And so on, through engineering and manufacturing development, production and deployment, and operations and support. There are many hurdles to make before a system is actually fielded. In some cases, it can take many, many years.

As one can see, the acquisition program of record is a complicated and complex process and can lead to a lengthy undertaking. However, the acquisition program of record has a proven track record as being effective in developing advanced technology systems. Examples include the Apache Longbow helicopter, M-1 main battle tank, the Combat Service Support Very Small Aperture Terminal (CSS VSAT) tactical satellite communication system, and a family of unmanned aircraft systems.

The two approaches to developing and procuring body armor are significantly different during requirements generation and procurement. Again, the requirements-generation process for an acquisition program of record is dictated by JCIDS, with its CBA, ICD, and JROC approval process. The requirements process for a commodity procurement can be less formal. In many cases, the combatant commands submit operational needs statements to Headquarters, Department of the Army (HQDA). From there, a purchase description is generated that specifies the requirements for the commodity, body armor in this case. ESAPI plates provide an example of this process.

Responsibility for procurement of a program of record item remains with PEO and its responsible PM throughout all the buys of the item. In the case of a commodity, DLA takes over procurement of the item after it has been proven, tested, initially procured, and employed.

We provide more details on how the Army, Marine Corps, and SOCOM each procures body armor and funds body armor RDT&E in the appendix.

Developing and Fielding Lighter Body Armor Would Require a Comprehensive R&D Strategy

A strategy to develop and field lighter-weight body armor must address several issues. These include the risks and costs involved in developing advanced materials, the adequacy of current body armor, and the uncertainty in the future body armor market.

The contractors and Natick and ARL personnel we spoke to felt that limits in current materials technology suggest that a technical breakthrough is required. If large reductions in body armor weight will require a breakthrough in materials technology, significant R&D funding will be required. However, current and planned funding for body armor R&D is relatively limited, and current body armor is considered adequate—even though there are some operational impacts (e.g., body armor weight, soft body armor coverage of vital body areas, soldier flexibility), today's body armor is effective.

Before vendors invest in required R&D to procure the next-generation body armor, they must have confidence that there will be a future body armor market. Industry by itself will not be able to develop the next generation of body armor. Some novel, out-of-the-box options are required that may lead to such a breakthrough. This requires efforts that are outside the usual acquisition and procurement processes.

Broad Agency Announcements (BAAs) are one method of soliciting body armor technological breakthroughs from private industry at a low cost to the government. For example, the Adaptive Execution Office (AEO) results in the transfer of DARPA technology to the warfighter through DARPA BAAs. To this end, AEO develops and employs novel processes, new

tools and techniques, and innovative business models. Currently, AEO seeks responses relating to four mission areas: adaptive systems, operationally focused system integration, accelerated system production technology, and comprehensive system assessment. Body armor could be added as a fifth mission area.

Another low-cost approach soliciting body armor technological breakthroughs from private industry is to use "challenges," as DARPA refers to them. There are essentially two models—an award prize for a stated goal or competition and a fund promising ideas through prototypes. The new Enhanced Combat Helmet, which represents a breakthrough technology in cranial protection, was developed as a result of industry response of a DARPA challenge. Both types of challenges can provide an economical and effective approach to developing R&D technology that requires breakthroughs, but may involve less certainty of success.

The development of lighter-weight body armor materials will probably require a comprehensive R&D strategy. By lighter-weight, we mean a greater than 20 percent reduction in weight. To achieve this reduced weight goal, several prerequisites must be satisfied:

- First, requirements should be focused on those threats currently observed in the theater or anticipated in the future. As we have seen in our discussion, requirements can be a driver of the body armor weight.
- Second, because the development of new materials that will lead to lighter-weight body armor is technologically difficult with many risks involved, a sustained, significant, and coordinated science and technology (S&T) effort is required. This should include centralized oversight and allocation of S&T funds.[19] Also, improved modeling and simulation (M&S) and testing must be performed.
- Third, a systems approach to the development must be used. For example, the current approach of separating body armor into a soft and a hard component should be merged. Historically, soft armor vests were developed first, then later, hard armor plates were added to the vest. It is possible that overall system performance could be improved with a more integrated design approach.
- Fourth, there needs to be a commitment by DoD to procure new body armor sets in significant numbers. Vendors need to see a market for the next-generation body armor before they will devote their time and money to researching ways to reduce the weight.

The Armament Enhancement Initiative (AEI) provides an illustrative example of the kind of program that is likely necessary to significantly reduce the integral weight of body armor.[20] AEI was an ammunition development program initiated in 1985 in response to concerns that U.S. tanks lacked an ability to penetrate newer models of Soviet tanks. The Program Manager for Tank Main Armament Systems (PM-TMAS) directed the RDTE efforts, as well as the follow-on procurements of ammunition.[21] Congress provided a sustained and significant

[19] Better coordination of S&T is currently being performed between the U.S. Army Research, Development and EngineeringCommand (RDECOM), U.S. Army Medical Command, and the Army's Warfighter Cross Service Equipment Board through the establishment of the Individual Soldier Ballistic and Blast focus area.

[20] Over the course of its history, the AEI resulted in several families of tank ammunition for both the 105-mm and 120-mm cannons (including the M829A1 "silver bullet" of Desert Storm fame) that provided very large improvements in terms of lethality against the emerging tank threats.

[21] R. Chait, J. Lyons, and D. Long, *Critical Technology Events in the Development of the Abrams Tank: Project Hindsight Revisited*, Washington, D.C.: Center for Technology and National Security Policy, National Defense University, December 2005.

AEI funding stream for 15 years that paid for a significant science and technology program.[22] The AEI program invested in the metallurgy, composites, propellant, and ballistics research that was necessary for the required large improvements. Additional investment was made in testing and test facilities to enable the identification of technical issues and to assess progress. In addition, very significant efforts were made in modeling and simulation to provide new analytic tools.[23]

In addition, the Army was committed to significant purchases of new tank ammunition as newer types were developed through the AEI program and became available. As a result, hundreds of thousands of tank rounds were procured, creating a multi-billion dollar market. Such a large market and the prospect of continued development and procurement contracts for new products every few years attracted several companies that competed for market share by way of cost and value.

Using the Procurement Process/R&D Funding as a Means to Lighten Body Armor

Candidate new materials exist for both hard and soft body armor that have the potential to reduce body armor weight. Currently, they are technologically immature for this application. In order to exploit these "leap-ahead" technologies, adequate R&D funding and development time are required, along with collaborative research both among Army labs and between Army labs and other service labs. Estimates of the weight savings that are probable for next-generation body armor weight cannot yet be reliably made. The current commodity procurement process appears adequate to provide the funding and management flexibility that are needed to develop the next-generation body armor.

If a modest reduction of plate weight appears feasible and the threat remains the same, new advanced technology plates are not necessarily needed. In such a case, DoD is best suited to stay with the commodity procurement approach. However, if the projected threat increases and the effects of body armor weight are shown to dramatically impact soldier combat performance, then an acquisition program of record is the best approach to developing the next generation of advanced technology body armor.

[22] The President's budget for fiscal year 2000 was the last one to include the AEI program. Funding under the same program element number continued, but with the name "Tank and Medium Caliber Ammunition."

[23] Chait, Lyons, and Long (2005) and personal knowledge of Bruce Held from experience in the program.

CHAPTER FOUR

Conclusions

In this chapter, we first present a comparison of the four approaches to lightening body armor discussed in Chapter Three, then we present our general conclusions, and finally we specifically address the eight issues raised in Section 125 of the Defense Authorization Act of Fiscal Year 2011.

Comparison of the Four Approaches

Our examination of the four approaches to lightening body armor—refining requirements, using modular configurations, improving testing, and improving materials—indicates that each has certain merits as well as limitations. Some of the nonmaterial solutions can be implemented today, but they involve risks. Others, such as improving materials, are longer-term solutions with unknown outcomes and costs. Figure 4.1 compares the different approaches in terms of what is involved in executing changes, what potential coordination is required, and what the estimates of weight reduction are.

Figure 4.1
Comparison of the Four Approaches to Reducing Body Armor Weight

Approach	Ease in Executing Change	Required Army Coordination	Estimated Weight Reduction	Comment
Refine requirements	Moderately difficult	DCS G-3, TRADOC	**Small to moderate (~10–20%)**	Consequence great if wrong
Use modular body armor configurations	Easy in principle	Field commanders, TRADOC	**Moderate to large (~20–45%)**	Questions remain about risks
Improve testing	Moderate	PEO Soldier, ATC	**Small (~5–10%)**	Requires coordination with other services, DLA, and SOCOM and DOT&E approval
Improve materials (R&D, procurement process)	Moderate (funding)	ASA(ALT), DCS G-8	**Unknown at present**	Long-term solution; appropriate procurement process depends on technological challenge

NOTES: ASA(ALT) = Assistant Secretary of the Army (Acquisition, Logistics and Technology); DCS = Army Deputy Chief of Staff.

RAND *TR1136-4.1*

In some respects, refining requirements is the most difficult approach to implement: Changing the processes necessary to meet requirements is not very difficult, but the decision to change a requirement in the first place is. A change from a currently accepted round as the driving threat that body armor must be capable of stopping to a less capable round (in terms of muzzle velocity, bullet type, or caliber) has serious consequences if the change is later shown to not be warranted and additional casualties occur.

The least difficult change to make is using modular body armor configurations. This is because the decision to use modular body armor has already been made. However, the risk associated with using this approach is largest. If a commander decides to use a less protective body armor configuration (i.e., a lower level BAPL) and his choice proves to be incorrect, who gets blamed? The other two approaches that we have considered—improving testing and improving materials—involve difficult and costly choices but should not lead to unfortunate operational outcomes.

Each of the approaches requires Army coordination before it can be implemented. Both refining requirements and using modular configurations require high-level coordination because of the consequences that are involved if the unanticipated occurs. Improving testing requires DOT&E approval, and developing improved materials requires funding and time.

With regard to the estimated weight reductions, a 10 percent weight reduction appears to be the most that one can plan on today through further improvements to existing hard and soft body armor.[1] A nonmaterial approach of using modular body armor configurations offers large weight reductions that can be achieved today. For example, going from BAPL 5 to BAPL 2 reduces weight by 14 pounds, or about 45 percent.[2] However, serious concerns remain about the risks involved in selecting the level of body armor protection. Similarly, changing the threat can dramatically change the required protection of the body armor and, consequently, its weight. Based on the threat levels, we estimate that a reasonable upper limit is a weight reduction of about 20 percent. However, one needs to appreciate that the threat level that is selected can change over time. With regard to testing, one vendor estimates that over-design due to the test's variability amounts to about one-half pound per plate; others feel that larger reductions may be possible. Consequently, we have to assume an upper limit of 10 to 20 percent. The long-term solution may involve new body armor materials. However, feasible weight reduction resulting from the introduction of new materials cannot be estimated today.

Greater increases in weight reduction may be possible if some of the approaches are considered synergistically. For example, a larger weight reduction should be achieved if the benefits derived from reduced requirements are combined with the benefits gained from improved testing coupled with modular configurations.

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[1] During interviews with hard body armor vendors, Natick Soldier RDE Center, and PM Soldier Protection and Individual Equipment, a consensus emerged that a 10 percent reduction in body armor weight was about the most that could be achieved today using a material approach.

[2] This weight reduction is based on a medium size body armor suite using XSAPI/XSBI plates. The percentage reduction will vary depending on plate model, type, and size.

General Conclusions

First, there is no "silver bullet" material solution available that can greatly reduce body armor weight. Vendors indicate that a 10 percent reduction appears feasible but is not easy to accomplish, where as a 20 percent reduction is not realistic.

Second, there are some nonmaterial solutions that are available that can result in a greater than 20 percent weight reduction. Modular body armor configurations can provide a 45 percent reduction if Body Army Protect Level (BAPL) 2 rather than 5 is selected by the field commander. The problem is that the choice of the appropriate BAPL for the combat conditions encountered is a difficult decision to make. Also, a large inventory of body armor vests and plates must always be available. It is a difficult logistics problem to provide the various plates and vests in all sizes to forward combat areas, where body armor is needed the most.

Third, a combination of material and nonmaterial approaches should result in greater weight reduction. If the plates are over-designed for the threat, then the testing procedures could be changed. This could result in thinner and lighter-weight plates passing new test procedures.

Fourth, a synergy of modular concepts may lead to greater weight reduction. Soft and hard body armor should be considered as one item and not two. Today's practice is to simply add hard plate inserts to soft vests. A systems approach needs to be conducted to design a single body armor concept.

Fifth, further reductions in weight will require a significant investment of money and time. Changes to the plate design might reduce the plate weight. For example, the plates might be tailored in terms of thickness, with the abdomen portion of the torso having a thinner plate thickness than the plate thickness protecting the chest area. Making variable-thickness plates would involve changing the manufacturing process and the testing procedures. These changes could require a significant investment of money and time.

Specific Issues Raised in Section 125 of P.L. 111-383

Issue #1: The requirement for lighter-weight body armor and personal protective equipment and ability of the Secretary of Defense to meet such requirements.

Response: (a) A nonspecific draft Army Capability Development Document (CDD) for Soldier Protection System is currently being coordinated; (b) the requirement for lighter-weight body armor needs to be strengthened; (c) vendors should be able to meet a requirement for 10 percent weight reduction; (d) requirements must reflect actual threat; (e) however, a larger reduction is difficult in the near term unless a modular approach is widely accepted.

Issue #2: Innovative design ideas for more modular body armor that allow for scalable protective levels for various missions and threats.

Response: (a) Synergy of soft and hard body armor by an integrating contractor may lead to lighter-weight modular designs; (b) the development of decision aids will help in the selection of body armor protection levels (BAPLs); (c) further use of an improved ORCA/MUVES

model should provide a better understanding of the critical injury areas and refine torso coverage by soft and hard armor, thereby reducing the weight of both armor types.

Issue #3: The need for research, development, and acquisition funding dedicated specifically to reducing the weight of body armor.

Response: (a) More R&D funds are needed than are currently being provided; (b) greater use of Broad Agency Announcements (BAAs, DARPA "challenges," and other R&D funding mechanisms should be used; (c) also important to motivate the contractors to incorporate innovation in their designs.

Issue #4: The efficiency and effectiveness of current body armor funding procedures and processes.

Response: While the Army may be designated as Executive Agent, research is stovepiped and spread across disjointed DoD R&D facilities, which need to be better coordinated.

Issue #5: Industry concerns, capabilities, and willingness to invest in the development and production of lightweight body armor initiatives.

Response: (a) Concern over lack of financial reward in current contracting approach in selecting winning contractors (lowest cost versus best performance); (b) more funds available for R&D; (c) clearly defined, incentivized requirements across all services.

Issue #6: Barriers preventing the development of lighter-weight body armor (including such barriers with respect to technical, institutional, or financial problems).

Response: Barriers to developing material solutions include (a) difficulty contractors face in producing lighter-weight body armor; (b) slow process in formalizing a new requirement to lighten body armor; (c) market size and maturity (ramp-up of latest body armor has been completed, and future sales are limited to refurbishments); (d) lack of incentive for vendors to assume risks; (e) understanding comprehensive soldier risks (load effects on soldier performance).

Issue #7: Changes to procedures or policy with respect to lightweight body armor.

Response: Use best value and weight criteria instead of lowest cost in selecting vendors.

Issue #8: Other areas of concern not previously addressed by equipping boards, body armor producers, or program manager.

Response: Need to (a) update 1977 findings on backface deformation (BFD); (b) develop field decision aids for deciding BAPL; and (c) validate and integrate battle trauma data with ongoing survivability research.

CHAPTER FIVE

Recommendations

We propose two types of recommendations—top-level and specific. Top-level recommendations are those that are applicable no matter what direction the next generation of body armor takes. The specific recommendations address specific issues or problems that we have identified during the course of performing our research. They should also be addressed no matter what direction the next generation of body armor takes.

Top-Level Recommendations

Increase body armor funding in RDT&E program elements for coordinated and mutually supporting service programs. First, in order to develop next-generation body armor that uses advanced technology materials and is significantly lighter than today's versions, the amount of RDT&E funding must be increased. The various RDT&E program elements also need to be better coordinated, and the various service efforts should be mutually supporting.

Make sure the threat level requirement is consistent with the threat environment being encountered in active theaters today and those anticipated in the future. Second, the threat level requirement should be consistent with the threat environment being encountered today and anticipated in the future. It may take many years to develop and employ lighter-weight body armor using new materials. One needs to be sure that the body armor that is developed can provide protection against the future threat.

Manage the requirements-development process to coordinate relevant stakeholders from concept to requirements definition. Third, the requirements-development process needs to be reviewed to ensure that coordination among the relevant stakeholder offices is continuous as requirements are developed. Making optimal trade-offs between protection, weight, ergonomic impact, and cost requires ongoing interaction among the user representative, the technical community, and the resource providers, from the start of requirements assessment to the publication of the requirements document.

Add performance criteria to contract award selection in addition to lowest cost. Fourth, performance—including weight—should be included as a contract award selection criterion when awarding production contracts for body armor. Currently, products that meet the threshold criteria are selected solely on a cost basis by DLA, so prospective producers have no incentive to improve body armor performance beyond the threshold.

Specific Recommendations

Consider Berry Amendment waivers in procuring soft body armor and personal protective clothing. First, the Berry Amendment (USC, Title 10, Section 2533a) requires DoD to

give preference in procurement to domestically produced, manufactured, or homegrown products, most notably food, clothing, fabrics, and specialty metals. Congress originally passed domestic source restrictions as part of the 1941 Fifth Supplemental DoD Appropriations Act in order to protect the domestic industrial base in the time of war. There have been numerous exemptions granted since its original passage, and the law now applies generally to textile materials, including those utilized in body armor.

The American Recovery and Reinvestment Act (H.R. 1), passed by both houses of Congress on February 13, 2009, included legislation offered by Congressman Larry Kissell (D-NC) mandating that any textile and apparel products contracted by the U.S. Department of Homeland Security be manufactured in the United States with 100 percent U.S. inputs. The "Kissell Amendment" was modeled on and picks up, with little or no modification, many of the specific provisions of the Berry Amendment.

We recommend that exceptions be made to the Berry and Kissell Amendments in the design and manufacture of soft body armor intended for U.S. service members to ensure that they are wearing the best, most durable, and most protective armor available in the world.

Update 1977 Prather study to reassess relationship between backface deformation and mortality. Second, the 1977 Prather study provided some correlation on mortality and backface deformation. However, this study looked only at soft body armor. By utilizing current threats and available body armor (soft and hard), a new study should provide a better understanding of the effectiveness of utilizing backface deformation as a criteria for appropriate protection of soldiers on the battlefield. We recommend that an updated study be performed.

Use ORCA/MUVES model to help devise decision aid for deciding appropriate BAPL at the unit level. Third, as discussed earlier, field commanders may be reluctant to utilize a BAPL lower than the maximum without some sort of decision support tool to back up their assessment. Operationalizing the ORCA/MUVES model will give commanders a tool that may increase mobility and lethality while ensuring survivability. A continued development of the ORCA/MUVES model is recommended, leading to a decision aid that the field commanders can use.

Establish comprehensive trauma data collection and analysis to better inform researchers, developers, and decisionmakers. Fourth, we recommend that a comprehensive trauma data collection and analysis process be established to better inform researchers, developers, and decisionmakers. A theater trauma system is in place for collecting data on trauma patients and implementation of a performance improvement program. Data collected on trauma patients included demographics, mechanism of injury, physiology, diagnostics, treatments, and outcomes and was placed into the Joint Theater Trauma Registry (JTTR). The collection process should be expanded to provide needed data to ascertain the effectiveness of body armor.

Conduct research to understand how body armor weight may increase probability of injury or death because of soldier and unit performance degradation. Finally, we recommend that research be conducted to better understand how body armor weight may inadvertently increase the probability of injury or death because of performance degradation. The research should include studying how combat loads affect performance through weight distribution and load carriage design, so that commanders can make more fully informed decisions about BAPLs. Also, further analysis is needed to determine whether aerobic and strength training can diminish the performance impacts of wearing body armor.

APPENDIX

Army, Marine Corps, and SOCOM Processes for Procuring Body Armor

The U.S. Army, the U.S. Marine Corps, and SOCOM follow DoD Instruction 5000.2 procedures for acquiring body armor. With rare exceptions, they all have similar processes for developing body armor from receiving needs statements from combat units to the development of designs and specifications to final acquisition. While each service has its own research and development for interim design, experimentation, and testing and the completion of performance specifications—summarized in Table A.1—they all coordinate with and depend on the expertise of the Army's Natick Soldier Center in development and use ATC for all FAT and most of the LAT testing. All employ DOT&E test protocols. The Special Operations Forces Support Activity (SOFSA) receives, warehouses, and distributes body armor. All contacting, testing, and acceptance are accomplished by the Program Manager, SOF Survival, Support, and Equipment Systems, at Natick, Massachusetts. The Army and Marine Corps use the Defense Logistics Command for the final steps.

Coordination among the services occurs periodically at a Cross-Service Warfighting Equipping Board. The Army and Marine Corps have started monthly meetings concerning body armor requirements, development, and specifications.

Table A.1
Summary of Army, Marine Corps, and SOCOM Processes for Procuring Body Armor

	Army	Marine Corps	SOCOM
Requirements	Combatant commands submit Statement of Needs to TRADOC Maneuver Center of Excellence (MCoE) that conducts cost-benefit analysis to prepare courses of action for a Capability Development Document (CDD)	Combat units submit a Universal Need Statement (UNS) or Urgent Universal Needs Statement (UUNS) to Systems Command's Deputy Commandant Combat Development and Integration (CD&I) Branch that completes a doctrine, organization, training, materiel, leadership and education, personnel and facilities (DOTMLPF) evaluation and affordability analysis. The analysis and recommended Courses of Action are presented to the Marine Requirements Oversight Counsel (MROC) for decision. DC CD&I then develops a CDD, CPD, Statement of Need or Urgent Statement of Need (USON) setting threshold and objective criteria.	Component and combatant commands submit combat needs requirements to SOCOM J8 Requirements. These can take the form of JCIDS, like Capability Documents or Combat Mission Need Statements (CMNS). After careful analysis and staffing, the requirements are presented at SOCOM Requirements Evaluation Board for deputy commander approval/disapproval.
Design development	PEO Soldier with RDECOM's input synthesizes the research and experiments on materials, design, manufacturing	Systems Command's program engineers, with Natick Soldier Center personnel and various research labs (NRL and ARL), research and experiment with materials, design, manufacturing.	Special Operations Research, Development, and Acquisition Center (SORDAC) designated PM at Natick coordinates detailed engineering and design development with vendors awarded specific development/production contracts.
Specifications	PEO Soldier prepares specifications in conjunction with TRADOC Maneuver Center of Excellence (MCoE)	Systems Command prepares contract specifications in conjunction with DC CD&I. All specifications are traced back to the requirements outlined in the requirements documentation.	PEO SOF Warrior Systems' (PEO-SW's) designated Program Manager (PM) and its Integrated Product Team (IPT) prepares performance specifications as part of the procurement package request. The performance specification is primarily derived from the user's capability document.
Testing	Aberdean Test Center (ATC) performs all FAT and most LAT testing (some outsourcing of LAT is permitted)	Aberdeen Test Center (ATC) performs all FAT testing based on DOT&E protocols. LAT testing can be done at NIJ Labs or at ATC based on type of test, schedule, and costs.	ATC is engaged to conduct FAT IAW DOT&E test protocols. ATC is SOCOM's preferred choice to conduct LAT unless schedule availability dictates use of a validated independent third-party lab.
Acquisition	RDECOM Contracting Center issues a Broad Agency Announcement (BAA) and Solicitation, Offer, and Award and awards contract for body armor as a commodity	Systems Command's contracting officers prepare Request for Proposal (RFP) and award contract. RDECOM Contracting Center can be utilized based on item expertise and internal manpower availablility.	With the procurement package request, SORDAC's Contracting directorate leads the solicitation phase. After source selection and customary reviews, the contracting officer will issue an award. The Special Operations Forces Support Activity (SOFSA) receives delivered body armor, conducts Non Destructive Inspections, and assembles into complete body armor kits.

Table A.2 shows a breakdown of the Army RDT&E funding for body armor research. The amount of funding devoted to RDT&E is small relative to the magnitude of the recent buys (approximately 2 percent of the procurement funding). Peak procurement funding totaled approximately $2 billion per year. This amount is small relative to the average amount of R&D that is spent for procurement of high-tech programs of record.[1]

Table A.2
Summary of Army Body Armor RDT&E Funding

		Funding ($ millions)						
Project	**Name**	**FY11**	**FY12**	**FY13**	**FY14**	**FY15**	**FY16**	**FY17**
ISN 6.1	Institute for Soldier Nanotech[a]	0.5	0.5	0.5	0.5			
ISN 6.2	Institute for Soldier Nanotech[a]	1.4	1.4	1.5	1.5	1.5		
H98 (6.2)	Warfighter Technology	6.8	6.9	6.4	6.3	6.4	6.6	6.7
H80 (6.2)	Ballistic Technology	2.2	3.2	4.9	5.2	5.6	5.2	5.2
H84 (6.2)	Materials Technology	2.4	2.2	4.0	4.0	2.0	1.0	1.0
J50 (6.3)	Future Warrior Tech Integration	6.7	7.7	8.7	9.1	9.3	9.4	9.6
H43 (6.1)	Ballistics Research	4.6	5.1	5.2	5.3	5.4	5. 5	5.6
FH2 (6.2)	Blast/Blunt Trauma Models	0	0.7	0.8	0.9	0.7	0.7	0.7
S53 (6.4)	PM Soldier Protection and Individual Equipment	4.8	not released					
S60 (6.5)	PM Soldier Protection and Individual Equipment	3.7	not released					
E25 (6.7)	MANTECH - Lightweight Body Armor	0.4	1.9	2.5	2.0			
Totals	Army Body Armor RDT&E	<33	<30	<35	<34	<31	<29	<29

SOURCE: R-2 RDT&E Budget; U.S. Army Natick Soldier RDT&E Center; Army Research Lab/WMRD.

[a] Only a portion of the funds are designated for research related to body armor.

Some RDT&E funding for body armor is also provided by the Marine Corps and SOCOM. The funds that the Marine Corps has devoted to body armor under Budget Activity 7 are $5.3 million in FY2011, $5.3 million in FY2012, $4.6 million in FY2013, $4.7 million in FY2014, $4.9 million in FY2015, $4.9 million in FY2016, and $5.5 million in FY2017. These funds do not reflect Navy research related to body armor. SOCOM has programmed $0.5 million per year for body armor research from FY2011 through FY2017. If these are included with the Army's amount, the total RDT&E is still relatively small relative to the size of the body armor procurement.

[1] We used the average ratio of R&D over procurement spending during the last decade as a surrogate for the typical ratio of R&D to procurement of high tech acquisition programs. From FY2001 to FY2010, the average ratio of R&D to Procurement spending in the Army was 0.34. (Office of the Under Secretary of Defense [Comptroller], Table 6-16, Army TOA by Appropriation Title—FY 1948 to FY 2016, National Defense Budget Estimates for FY 2012, March 2012, Washington, D.C.)

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